INTRODUCTION

This support document supplements Chapter 61 Water Quality Standards (567) (effective November 11, 2009). The two major subjects discussed are the Wasteload Allocations (WLAs) and the modeling theory. Iowa Department of Natural Resources does WLAs for facilities that discharge treated wastewater into waterways in order to assure that the permitted effluent limits meet applicable state Water Quality Standards. The calculation of a WLA is divided into three steps. Step one uses hand calculations, step two uses the DNR's Modified Iowa Model, and step three uses the Vermont QUAL-II Model.

There are two mathematical modeling theories or computer programs that are used by the Department. DNR's Modified Iowa Model can be used as a quick screening tool to eliminate the advanced wastewater treatment requirements for permitted discharges on potentially water quality limited stream segments. Staff will develop final WLAs for dischargers on WQ-based stream reaches using the Vermont QUAL-II Model. The Vermont version of QUAL-II meets all the requirements of an appropriate model for the State of Iowa since it includes excellent algal kinetics, preferential uptake of ammonia, and the simulation of all inorganic and organic forms of nitrogen and phosphorus.

This document is posted on the Iowa Department of Natural Resources Environmental Services Division website in the Water Quality Bureau section.

WASTELOAD ALLOCATIONS

Wasteload allocations are determined for wastewater treatment facilities or other permitted discharges that discharge into waterways in order to assure that applicable state Water Quality Standards are met within the watershed basin. Wasteload allocation analyses are performed for monthly conditions using the projected 20 year Average Dry Weather (ADW) and Average Wet Weather (AWW) wastewater discharge flows entering a receiving stream which is at the design low stream flow or protected flow regime. The acute, chronic, and human health wasteload allocation calculations will use the applicable design low flow noted in the following Table.

Table IV-1 Design Low Stream Flow Regime

Type of Numerical Criteria	Design Low Flow Regime
Aquatic Life Protection (TOXICS)	
Acute	$1Q_{10}$
Chronic	$7Q_{10}$
Aquatic Life Protection (AMMONIA – N)	
Acute	$1Q_{10}$
Chronic	$30Q_{10}$
Human Health Protection & MCL	
Non-carcinogenic	$30Q_5$
Carcinogenic	Harmonic mean
Bacteria	
E. coli	$7Q_{10}$
CBOD	$7Q_{10}$

$1Q_{10}$ means 1-day, 10-year low flow,
$7Q_{10}$ means 7-day, 10-year low flow,
$30Q_5$ means 30-day, 5-year low flow,
$30Q_{10}$ means 30-day, 10-year low flow,
Harmonic Mean is calculated by dividing the number of daily flows in the database by the sum of the reciprocals of those daily flows.
CBOD = Carbonaceous Biochemical Oxygen Demand.

Care must be taken in selecting the design discharge flow, which would be expected to be entering the receiving stream during the design low stream flow or protected flow conditions. Most WLA calculations will use the ADW or AWW design flows. Design flows are obtained from facility plans, engineering reports, or constructed permits. IDNR staff should approve the design flows used for wasteload allocation calculations.

Wasteload allocation analysis will be performed on the receiving streams designated as Class A, B, and/or C with existing or proposed wastewater discharges and on the tributaries classified as general use that receive wastewater discharges. This analysis will incorporate accurate consideration of field conditions for each type of stream. The specific assumptions and considerations that are part of the analysis are discussed below.

Assumptions

In order to determine wasteload allocations for discharges within the state, specific assumptions are required. Identification of the major items required to evaluate and determine wasteload allocations are identified in the following list.

1. Determination of design low stream flows is required for each stream segment modeled. The calculation of low flows on ungaged stream reaches are based on data from Plate 3 and 4 of the USGS publication, "Annual and Seasonal Low-Flow Characteristics of Iowa Streams," March 1979. Low flow at gaged stream locations is obtained from the USGS Open-File Report "Statistical Summaries of Selected Iowa Streamflow Data".

   For some waterways, a Protected Flow (P.F.) has been established that replaces the statistical based low flows found in the USGS publications. Protected flows can be found in the document titled Protected Flows for Selected Stream Segments, February 1, 1996. The Protected Flows will be used in lieu of the natural flows noted in Table IV-1 unless the statistical natural flow is larger (higher). For example, a small designated stream may have a $7Q_{10}$ = 0.2 cfs, $1Q_{10}$ = 0.15 cfs, $30Q_{10}$ = 0.3 cfs, $30Q_5$ = 0.6 cfs and a P.F. = 0.5 cfs. The 0.5 cfs protected flow would be substituted for the $1Q_{10}$, the $7Q_{10}$, and the 30 Q_{10}, and the $30Q_5$ would be equal to 0.6 cfs.

2. The major objective of the hand calculations and the modeling activities is to assure that Iowa Water Quality Standards are met with the permitted and future effluent discharge flows. Modeling activities determine an allowable wasteload allocation by varying the allocation for a discharger (or dischargers) until the water quality model demonstrates that the instream oxygen concentrations would be maintained above the dissolved oxygen criterion values. In addition, the modeling will determine instream ammonia nitrogen concentrations below the water quality criteria levels in the designated stream segments at the critical stream flow conditions as shown in Table IV-1, or at the protected low flow. Hand calculations directly set the wasteload allocation through a dilutional or mass balance relationship.

3. One hundred percent of the stream's low flow is used to assimilate the nonconservative pollutant Carbonaceous Biochemical Oxygen Demand (CBOD) in the wastewater discharge. The stream flow contained in the defined mixing zone is used to assimilate the conservative and toxic pollutants such as ammonia nitrogen (NH_3-N), TRC, metals, cyanide, and toxics. Specific water quality-based $CBOD_5$ and NH_3-N permit limits will be noted as long as the calculated values are more stringent than those assumed for normal domestic standard secondary treatment facilities (see paragraph 7 below). For those stream reaches with a protected flow, the greater (larger) flow value (natural or protected flow) will be used. Continuously discharging sources of wastewater are included in the modeling procedure (i.e. continous discharge lagoon, activated sludge, non-contact cooling water). Most waste stabilization ponds treating typical domestic wastewater and having 180 day controlled discharge capabilities are normally assumed not to be discharging at low stream flow conditions.

   The wasteload allocation resulting from the hand calculation or modeling calculations will be the basis for establishing both the maximum and the average loading and concentration which a facility could discharge.

4. Ultimate carbonaceous CBOD is assumed to be 1.5 times the $CBOD_5$. This ratio may be changed if site specific data indicates a different value would exist for a particular treatment process or waste characteristic.

5. Average stream temperature and pH are assumed to be approximated by the following table unless impacted by a thermal type discharge. Table IV-2 represents monthly average values from ambient monitoring data contained in the EPA STORET data system.

Table IV-2
Statewide pH and Temperature Values

Month	pH	Temp° C
January	7.8	0.6
February	7.7	1.2
March	7.9	4.3
April	8.1	11.7
May	8.1	16.6
June	8.1	21.4
July	8.1	24.8
August	8.2	23.8
September	8.0	22.2
October	8.0	12.3
November	8.1	6.0
December	8.0	1.6

6. In order that the reaeration rate constant be applicable to winter time ice conditions, the amount of ice cover on the stream is estimated. It is assumed that the effective amount of aeration should be inversely proportional to the percentage of ice cover. The winter reaeration rate constant for each stream reach is then determined by multiplying the temperature corrected rate constant by the adjusted fraction of open water in the reach. Experimental data was used to find the adjusted fraction of the open water in the reach. Ice cover estimates are based upon general climatological conditions for the basin and upon field observations. Open water fraction (ICE) is equivalent to $1-\left(0.95\times\frac{\text{percent ice cover}}{100}\right)$.

Example:

Winter: 100% ice cover results in open water fraction of 0.05

Summer: 0% ice cover results in open water fraction of 1.0

7. Since limited data is available to describe each individual wastewater treatment facility's effluent dissolved oxygen concentrations, the following values were assumed for each class of wastewater dischargers:

Wastewater Treatment Type	Summer DO (mg/l)	Winter DO (mg/l)
Secondary Treatment	3.0	4.0

Advance Treatment	5.0	6.0
Aerated Effluents	6-8	6-8
Industrial Plant	Each Discharge Handled Individually or Varies	

8. From analysis of available effluent data it has been assumed that a well operated and maintained secondary treatment plant treating normal domestic wastewater should be able to achieve 10-15 mg/l of NH_3-N in July and August and 15-20 mg/l of NH_3-N from September through June. Special consideration will be given when monitoring data from a wastewater treatment facility is greater than these levels.

9. Best practicable or available technology effluent limitations described by EPA guidelines are used for industrial dischargers when they are available and sufficient. Otherwise, the actual allowable wasteload required to meet stream standards is determined and identified as the wasteload allocation for that discharger. For municipal and industrial discharges with toxic parameters on streams classified as only general use, the allowable wasteload will be based on data contained in the U.S. EPA 304(a) criteria documents. These criteria documents will be used to determine in stream toxic criteria for general use streams.

10. The background water quality of the streams being modeled was assumed to have saturated dissolved oxygen concentrations, an ultimate CBOD concentration of 6.0 mg/l, and an NH_3-N concentration of 0.0 mg/l (July and August) and 0.5 mg/l (September through June).

11. The water quality of the groundwater contribution was assumed to have a $CBOD_5$ of 4 mg/l and an NH_3-N concentration of 0.0 mg/l (July and August) and 0.5 mg/l (September through June).

12. Mixing of wastewater and tributary flows with the main body of water is site specific and it is based on the allowed percentages noted in Chapter 61, WQS. Mixing is not assumed to be complete and instantaneous.

13. Uniform lateral and longitudinal dispersion (plug flow) is assumed for the stream constituents as they move downstream.

Wasteload Allocation Procedures

The wasteload allocation procedure section is divided into two subsections, conventional pollutants and toxics. This division is necessary because the Water Quality Standards (Chapter 61) require different instream criteria to be met at different locations in the receiving stream.

A. Conventional Pollutants: The calculation of a wasteload allocation for conventional pollutants will consider the instream dissolved oxygen impacts of carbonaceous biochemical oxygen demand (CBOD), ammonia nitrogen (NH_3-N), and any other oxygen demanding materials. The wasteload allocation for NH_3-N and other oxygen demanding materials is also addressed in the Toxics section, as these pollutants are also defined as toxics. It should be noted that this section of the wasteload allocation procedures does not consider other types of conventional pollutants, such as suspended solids, oil, and grease, because these pollutants are assumed to have little oxygen demand.

The wasteload allocation of the oxygen demanding pollutants are determined directly from the results of water quality models which account for the fates of the pollutants as they move down the receiving stream.

The two water quality models used to determine wasteload allocations are QUAL-II and Modified Iowa. They require additional data on algal kinetics and are limited to short stream reaches. Due to a lack of algal kinetic rate constants on many stream reaches, the extensive number of designated stream reaches in Iowa, and other factors, a sequencing/screening approach is being used to arrive at the final WLA. The sequencing of calculating a WLA is divided into three different steps. Step one uses hand calculations, step two uses the Modified Iowa model, and step three uses the QUAL-II model. Any WLA, new or recalculated, for any continuous discharging treatment facility is determined by following the sequence. Requests for a WLA will be handled as soon as possible. However, if a back log begins to occur, all requests will first be hand calculated (if necessary). This should address at least 50% of all requests. The remaining requests will be modeled with Modified Iowa and by the QUAL-II model if required.

1. Hand Calculations

The use of hand calculations is intended to provide a quick method to determine if a CBOD discharge of standard secondary or BPT/BAT[1] from the treatment facility is causing a water quality violation. This step could be skipped if the treatment facility is known to be causing a water quality violation, or if it is felt that the facility obviously requires advanced treatment. This calculation, as with the use of the water quality models, will be performed using the design low stream flow ($7Q_{10}$) or protected flow, the treatment facilities design dry and wet weather flow (if applicable), the appropriate standard secondary $CBOD_5$, and assumed ammonia levels. With the various alternative treatment limits allowed in the definition of standard secondary, the specific permitted $CBOD_5$ levels for the selected (or expected) type of treatment must be used in the hand calculations. This hand calculation approach uses a conservative assimilation rate of $CBOD_5$ (20 lbs/d/cfs) which has been derived from past modeling results.

a. Available Stream Capacity

Staff will calculate the available stream capacity for $CBOD_5$ below the discharger in question by the following relationships. $CBOD_L$ is the stream capacity (or loading) carbonaceous BOD_5 in pounds per day.

For $CBOD_5$

$$(Q_u + Q_d)\ 20\ \text{lbs/d/cfs} = CBOD_L \qquad (1)$$

where:

Q_u = Critical stream flow, cfs

Q_d = Dry weather design discharge flow, cfs

$CBOD_L$ = Stream capacity carbonaceous BOD_5, lbs/day

[1] BPT = Best Practical Treatment are EPA derived minimum treatment levels that are required for both municipal and industrial wastewater treatment facilities. BAT = Best Available Treatment are EPA derived levels for industry.

b. Treatment Facility Loading

The loading from the treatment facility at its specific standard secondary level is given by the following equation.

For BOD_5

$$(CBOD_5)(8.34)(Q_d) = CBOD_e \tag{2}$$

where:

$CBOD_5$ = Technology or standard secondary $CBOD_5$, mg/1
Q_d = Dry weather discharge flow, mgd
$CBOD_e$ = Carbonaceous BOD_5 in the effluent, lbs/day
8.34 = Conversion factor

c. Stream Capacity vs. Effluent Loading

If the stream $CBOD_5$ capacity ($CBOD_L$) above is larger than the technology or standard secondary $CBOD_5$ ($CBOD_e$), the stream is termed effluent limited for CBOD and no additional modeling is required. The effluent limitation for $CBOD_5$ will be the level set for standard secondary or the technology level.

If according to the above comparison the stream is not effluent limited, the stream should be modeled using the Modified Iowa model. However, unusual factors or stream conditions might warrant undertaking the next calculation step even if the stream is effluent limited. These unusual conditions might include: several dischargers within close proximity, discharge of large algal concentrations, discharge of elevated ammonia nitrogen levels, and loadings to the stream at or near stream capacity.

<u>2. Use of Modified Iowa Model</u>

When it is found that a treatment facility cannot discharge at a standard level, the staff will set up and run the Modified Iowa model described in greater detail below. For most dischargers, the previous model runs of 1976-1982 can be used as the basis input data. Minor modifications in data formatting are required to incorporate the new algal relationships. The Modified Iowa program will only be used on the stream reach below the discharge, not the entire river basin.

For each discharger, a monthly or seasonal (spring/fall, summer and winter) run normally will be made using the same dry and wet weather design flow as used in the hand calculations above. These monthly or multi-seasonal runs are necessary because of the monthly or potential seasonal ammonia nitrogen wasteload allocations developed in the Toxics sections. If the seasonal run was performed, the month that has the most stringent conditions should be used to represent the specific season. It is necessary to calculate the toxics based WLA for ammonia nitrogen for use in the modeling of conventional pollutants. In many instances, the protection of the ammonia acute and chronic criteria will be more restrictive than the oxygen demand exerted by the ammonia.

Calibrated rate constants and literature values found in Table IV-3 (page 71) will be used for the modified model. Detailed calibrations will be carried out only for the QUAL-II model. The purpose of the modified model is to be a quick modeling exercise with minimum staff time. Reiterative model runs will be made varying effluent $CBOD_5$ from standard secondary and varying NH_3-N to more stringent levels until model responses shows that dissolved oxygen water quality standards are met in the designated reach.

If the modeling demonstrates that standard secondary treatment will meet the water quality standards, then that level will be the effluent limit for the treatment facility. If the modeling shows that advanced treatment is required, the stream reach will be modeled using the QUAL-II program to determine the final wasteload allocations.

3. Use of the QUAL-II Model

When it is found that a treatment facility cannot discharge at a standard secondary level as evaluated by the above two calculations, then staff will set up and run the QUAL-II model described above. As with the Modified Iowa model, QUAL-II will be run only on the stream reach below the discharger. It is within this short reach that the steady state assumptions used in the model are valid.

Setting up the stream run under QUAL-II format requires additional staff effort. However, some of the physical stream data found in the Modified Iowa model's stream run will be used with the QUAL-II stream run. Whenever possible, calibrated rate constants will be used. These calibrated values can come from data obtained from intensive stream surveys on the receiving stream, from calibration data on similar streams, or from literature values shown in Table IV-4 (pages 83-84). The same dry and wet weather design flow and background ammonia nitrogen values will be used, as above.

For each discharger, April through June (Spring), September through October (Fall), July and August (Summer), and November through March (Winter) model runs normally will be made varying the effluent $CBOD_5$ (and NH_3-N if necessary) if the model response shows that dissolved oxygen water quality standards are met in the designated reach. The final wasteload allocation will be the combination of $CBOD_5$ and NH_3-N which just meet the standards.

Specific NH_3-N limitations will be noted in the wasteload up to the standard secondary range mentioned above (15 mg/l summer and 20 mg/l winter and spring/fall). This will indicate the available stream capacity for NH_3-N and allow for careful design of nitrification facilities. $CBOD_5$ limitations will be noted as carbonaceous or inhibited values except for certain industrial facilities for which BPT/BAT limits are expressed as BOD_5. An attempt will be made to establish a $CBOD_5$ to BOD_5 relationship for each industry for use only in modeling of the stream's assimilative capacity.

B. Toxic Parameters: The wasteload allocation (WLA) for toxic parameters will not require the use of the two above mentioned models. However, it is necessary to determine the characteristics of the regulatory Mixing Zone (MZ) and Zone of Initial Dilution (ZID). The regulatory MZ will be determined the default values noted in Chapter 61, WQS, from data supplied by the applicants, or from use of the MZ model noted in Appendix B, Mixing Zone Studies. Department staff will use the default values or practiced use stream characteristics obtained from file information unless the applicant provides additional data that demonstrates that the characteristics of the outfall or the discharge location do not match the assumptions used in the development of this model. Other models will be used where appropriate or as they become available.

The Appendix presents the basic field data requirements of a MZ study to be provided by an applicant for recalculation of the local MZ. The purpose of the recalculation is to more closely approximate the local MZ using site specific data instead of statewide data. Contact should be made with the Department's Water Resources Section prior to beginning any field study.

The calculations of toxic WLAs involves the incorporation of the ‘regulatory’ MZ and ZID for each wastewater treatment facility, the design effluent flow rates, and the applicable acute and chronic water quality criteria. The determination of the MZ and ZID are presented in a separate section (pages 51-53). This Toxics section uses these defined zones and the corresponding flow in establishing the WLAs for toxics.

Calculations:

As noted in Subrule 61.2(4) of the Water Quality Standards, the chronic criteria must be met at the boundary of the MZ and the acute criteria must be met at the boundary of the ZID. A simple mass balance of pollutants will be used to meet these boundary conditions.

$$C_bQ_b + C_oQ_o = C_s(Q_b + Q_o) \qquad (3)$$

where:

C_b = Background concentration, µg/l
Q_b = Stream flow in the MZ or ZID, cfs
Q_o = Effluent flow, cfs
C_s = Applicable water quality standard, µg/l
C_o = WLA concentration, µg/l

This equation is solved four times for C_o: one time each for ADW acute, ADW chronic, AWW acute, and AWW chronic. The results are wasteload allocations for the protection of the acute criteria and wasteload allocations for the protection of the chronic criteria. These wasteload allocation values are then carried forward to the Permit Derivation Procedure section (pages 55-56).

C. Ammonia Nitrogen: Special consideration must be given to the calculations of wasteload allocation for ammonia nitrogen. First, water quality standards list the ammonia criteria as a function of pH and/or temperature because of the influence these parameters have on the toxic form of ammonia (unionized). Therefore, it is necessary to establish the applicable 'average' instream pH and temperature values of the designated stream segment receiving the effluent before the acute and chronic ammonia criteria can be selected. After the adoption of the 2000
new ammonia criteria, the ammonia criteria will be calculated monthly based on pH and/or temperature values. As a result, the ammonia WLAs will also be monthly instead of seasonal.

Second, the Mixing Zone (MZ) flow and the Zone of Initial Dilution (ZID) flow are a function of the dilution ratio of the receiving stream to the effluent. This dilution ratio is defined in Chapter 60 of the department rules for a specific discharger as the ratio of the critical stream flow to the effluent design flow. As shown in Table IV-1 for ammonia, the chronic and acute wasteload allocations are calculated based on different design low stream flows, i.e. $30Q_{10}$ stream flow for chronic WLA's and $1Q_{10}$ stream flow for acute WLA's. The dilution ratios for ammonia are calculated using $30Q_{10}$ or $1Q_{10}$ stream flow and the effluent discharge flow as discussed below.

1. Dilution Ratios

The flow used in the wasteload allocation calculations for the MZ and ZID vary with the type of dilution ratio. The discharger will be separated into one of three types based on the river and discharge flows:

a. Type 1: The ratio of stream flow to discharge flow is less than or equal to 2:1 -
MZ is 100% of the $30Q_{10}$ ZID is 5% of the $1Q_{10}$

b. Type 2: The ratio of stream flow to discharge flow is less than or equal to 5:1 and greater than 2:1 –
MZ is 50% of the $30Q_{10}$ ZID is 5% of the $1Q_{10}$

c. Type 3: The ratio of stream flow to discharge flow is greater than 5:1 –
MZ is 25% of the $30Q_{10}$ ZID is 2.5% of the $1Q_{10}$

2. Mixing Zone: Boundary pH and Temperatures

For all three types of MZ ratios noted above, the pH and temperature values used to calculate the water quality standards for the boundary of the mixing zone are defaulted to the statewide background values (for statewide values, see Table IV-2) unless local values or regional values are provided by the discharger.

a. *Local Values:* If the applicant desires that local values be used, they must supply a minimum of 2 years of pH and temperature readings and sample at least once a week. Preferably, the readings will be obtained during the low flow conditions will be typical of 24-hour conditions. Monitoring values may be obtained either from upstream of the outfall and the discharge or from the approximate location of the downstream limits of the ZID and the MZ.

b. *Regional Values:* If a facility, at a reasonable distance upstream of the applicant, has supplied background readings of pH and temperature that the department believes can be used as background, these readings will be used instead of the statewide averages. Normally readings at the end of an upstream facility MZ will not be used as background for the facility unless these readings are from close proximity to the applicant's outfall.

3. Zone of Initial Dilution: Boundary pH and Temperatures

The acute water quality criteria for ammonia will be based upon one of the following methods:

a. For Type 1 facilities, the acute water quality criteria for ammonia will be calculated based on the effluent pH and temperature values.
b. For Type 2 and 3 facilities, the acute water quality criteria for ammonia will be based on a pH calculated using the following equation.

$$\text{ZID pH} = -\text{LOG}\{0.5 * [10^{-(\text{background pH})} + 10^{-(\text{discharge pH})}]\} \qquad (4)$$

$$\text{TEMPERATURE} = \frac{(F_B * T_B) + (F_D * T_D)}{F_B + F_D} \qquad (5)$$

where:

F_B = Background Flow in ZID, cfs
T_B = Background Temperature, °C
F_D = Discharge Flow, cfs

T_D = Discharge Temperature, °C

4. Calculation of the Wasteload Allocation

$$C_bQ_b + C_oQ_o = C_s(Q_b + Q_o) \tag{6}$$

where:

C_b = Background concentration, mg/l
Q_b = Stream flow in the MZ or ZID, cfs
Q_o = Effluent flow, cfs
C_s = Applicable water quality standard, mg/l
C_o = WLA concentration, mg/l

This equation is solved for C_o, resulting in wasteload allocations for the protection of both the acute and chronic criteria. These wasteload allocation values are then carried forward to the Permit Derivation Procedure section (pages 55-56).

5. Visible Dye Studies

Where visible dye studies have been done, the ammonia WLA calculations will use the percentage of stream flow in the MZ study as the MZ percentage at the critical design flow. If an analytical Fluorometer dye study is performed, the study results projected to the $30Q_{10}$ flow regime will be used to calculate the MZ flow. This MZ flow will be that value associated with diluting the effluent concentration to the maximum dye concentration at the MZ boundary. This is the required stream flow necessary to assure that the water quality standards are not exceeded at any location across the MZ boundary.

6. Final Ammonia Nitrogen WLA

Once the above input values are determined, the mass balance calculations, the ammonia decay relationship, or the algal uptake equation can be used to arrive at the applicable ammonia nitrogen (NH_3-N) WLAs. The ammonia decay and algal uptake equations used in the modified Iowa Model or QUAL-II model will account for the limited loss of ammonia in a general use reach. These equations will be used when a WLA indicates an ammonia limit more stringent than secondary treatment. It is important to point out that even though the ammonia WLAs are calculated monthly, the QUALII model will only be run seasonally. These seasons are: Summer (July through August), Winter (November through March), and Spring/Fall (April through June/September through October). The WLA calculations will assure that the acute criterion is met by using the allowed stream flow of the ZID, and that the chronic criterion is met by using the dilution of the flow contained in the MZ.

D. Total Residual Chlorine: Total Residual Chlorine (TRC) effluent limits will be calculated for any wastewater treatment facility discharging TRC into or impacting one of the four Class B waters and general uses. The applicable stream standard criteria are listed in Subrule 61.2(5) of the Water Quality Standards.

Calculations

Two types of calculations are available for determining effluent limits: hand calculations, noted above for toxics, and first order decay of TRC. The Iowa Department of Natural Resources (IDNR) has a spreadsheet available on Microsoft Excel to solve for the TRC decay equation when it is applicable. The TRC decay equation is only used to calculate TRC decay in the general use reach. Background flow, defined as the sum of all upstream flows and any incremental flows along the modeled reach, can be added at one of the three reach entries on the Microsoft Excel spreadsheet. The incremental flows should be included at the appropriate distance below the discharge. Most calculations will use the mass balance hand calculations for Toxic Parameters (pages 12-13) described previously.

It is important to point out the major change regarding TRC WLAs. In addition to the TRC decay calculations for the general reach, a TRC loss of 300 µg/l is assumed in the Zone of Initial Dilution (ZID) and the Mixing Zone (MZ) of designated streams.

Two sets of example calculations will be shown for TRC: one for a general use water receiving an upstream wastewater treatment plant discharge with a zero background flow, and one for a discharger to a general use water on which a background or upstream flow exists.

TRC Calculations with Zero Background Flow

Two steps are used in the calculation of a TRC Wasteload Allocation (WLA) for a general use water receiving an upstream wastewater treatment plant discharge with a zero background flow. The first step is needed only if the discharge is directly into a designated stream. Both the mass balance equation (including

300 µg/l TRC loss) and the TRC decay equation are used in these situations. The $7Q_{10}$ and $1Q_{10}$ flows will be used in the following examples. The calculation of a TRC WLA will use the applicable design low flow.

First, the $WLA_{chronic}$ and WLA_{acute} values are calculated using the modified TRC mass balance equation in the designated portion of the receiving stream. Second, the more stringent $WLA_{acute\ or\ chronic}$ value is used in the TRC decay equation to calculate the allowable WLA just downstream of the outfall in the general reach. The overall situation for this type of WLA is shown in the TRC Decay with Zero Background Flow Diagram Examples (Diagrams 1, 2, and 3).

First Step:

The following modified TRC mass balance equation is used for solving for C_o.

$$C_bQ_b + C_oQ_o = C_s(Q_b + Q_o) + 300\ C_o \qquad (7)$$

where:

C_b = Background TRC concentration in Class B stream, µg/l
Q_b = Stream flow in the mixing zone, zone of initial dilution, or general class stream, cfs
Q_o = Effluent flow, cfs
C_s = The water quality standard concentration in the mixing zone or zone of initial dilution, µg/l
C_o = WLA TRC concentration, µg/l

Additional information about modified TRC mass balance equation:

C_b and Q_b are background levels
C_o and Q_o are discharge levels
C_s is the water quality standards (chronic or acute)

Example of modified TRC Mass Balance Equation:

The modified TRC mass balance equations are calculated for the Mixing Zone (MZ) and Zone of Initial Dilution (ZID) to find the chronic wasteload allocation and the acute wasteload allocation.

WLA $_{chronic}$ Calculation Example (using the MZ):

(This calculation must be done for both ADW and AWW flows.)

where:

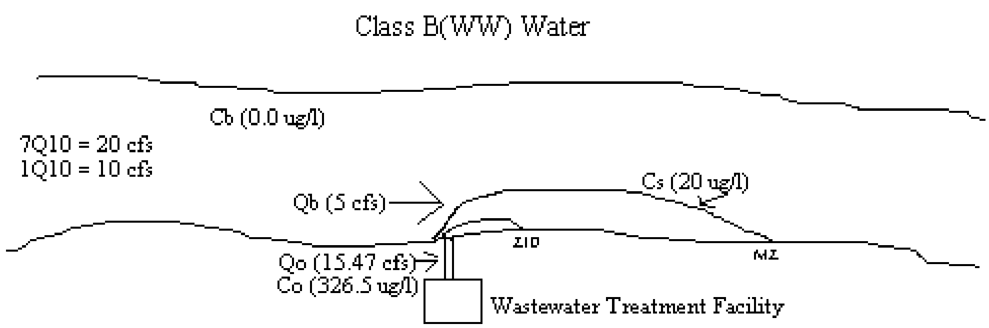
using $7Q_{10}$ = 20 cfs, $1Q_{10}$ = 10 cfs
C_b = 0.0 µg/l
$Q_b = ¼(7Q_{10}) = 20/4 = 5$ cfs
Q_o = 10 mgd (15.47cfs)
C_s = 20 µg/l chronic criterion

$C_bQ_b + C_oQ_o = C_s(Q_b + Q_o) + 300\ C_o$
$(0.0)5 + C_o(15.47) = 20(5 + 15.47) + 300(15.47)$
$0 + C_o(15.47) = 20(20.47) + 300(15.47)$
$C_o = \frac{20(20.47)}{15.47} + 300$
C_o = 326.46 = 326.5 µg/l WLA $_{chronic}$

WLA $_{chronic}$ Diagram for Shoreline Discharge:

Diagram 1 illustrates a shoreline discharge to a designated stream. The following diagram illustrates the above WLA $_{chronic}$ Calculation Example.

Diagram 1:



KEY:

$7Q_{10}$ = 20 cfs
$1Q_{10}$ = 10 cfs
C_b = Background TRC concentration, ug/l
Q_b = Stream flow in MZ, cfs
Q_o = Effluent flow, cfs
C_s = Water quality standard concentration in
the MZ, ug/l

WLA $_{acute}$ Calculation Example (using the ZID):

(This calculation must be done for both ADW and AWW flows.)

where:

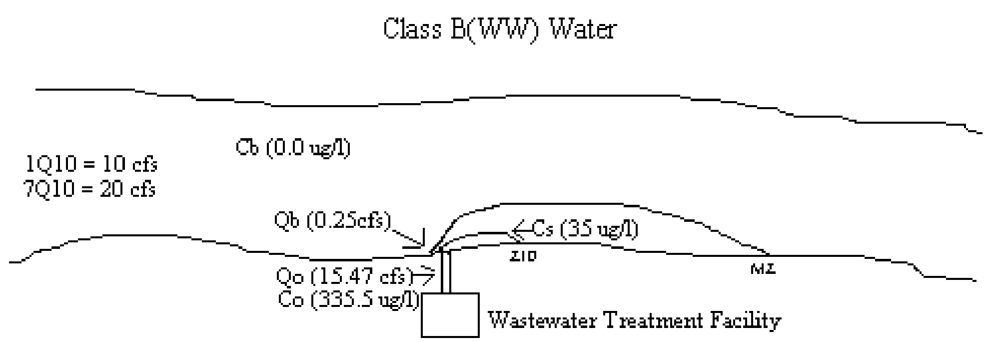
using $1Q_{10}$ = 10 cfs
C_b = 0.0 µg/l
Q_b = $1/40(1Q_{10})$ = 10/40 = 0.25 cfs
Q_o = 10 mgd (15.47 cfs)
C_s = 35 µg/l acute

$C_bQ_b + C_oQ_o = C_s(Q_b + Q_o) + 300\ C_o$
$(0.0)0.25 + C_o(15.47) = 35(0.25 + 15.47) + 300(15.47)$
$0 + C_o(15.47) = 35(15.72) + 300(15.47)$
$C_o = \frac{35(15.72)}{15.47} + 300$
C_o = 335.5 µg/l WLA $_{acute}$

WLA $_{acute}$ Diagram for Shoreline Discharge:

Diagram 2 illustrates a shoreline discharge to a designated stream. The following diagram illustrates the above WLA $_{acute}$ Calculation Example.

Diagram 2:



KEY:

$1Q_{10}$ = 10 cfs
$7Q_{10}$ = 20 cfs
C_b = Background TRC concentration, ug/l
Q_b = Stream flow in ZID, cfs
Q_o = Effluent flow, cfs
C_s = Water quality standard concentration in the ZID, ug/l
C_o = WLA acute, ug/l

Second Step:

The decay model uses a standard first order expression in which the time of travel in the stream reach is incorporated into the calculations. The model expression noted in the EPA's '*Technical Guidance Manual for Performing Wasteload Allocations; Book 2, Chapter 3, Toxic Substances*" June 1984, Appendix D, is used for TRC decay. The TRC decay equation is used when there is a discharge to a general use water (having zero flow). The decay equation will project the amount of TRC loss along the general use reach. The resulting WLA is more relaxed than the WLA calculated in the mass balance equation for the direct discharge to the designated reach. The following TRC decay equation is used, solving for C_d.

$$C_d = C_o e^{(kt)} \qquad (8)$$

where:

C_d = TRC upstream discharge concentration at time t, µg/l
C_o = WLA TRC concentration, µg/l
k = Decay rate constant, day $^{-1}$
t = Time of travel in modeled reach, day

The more stringent of the $WLA_{\text{acute or chronic}}$ from the first step is used in the second step. For these examples, the more stringent of the $WLA_{\text{acute or chronic}}$ is the WLA_{chronic} value of 326.5 µg/l. This value will be used for C_o in the TRC decay with zero background flow example.

TRC Decay with Zero Background Flow Example:

where:

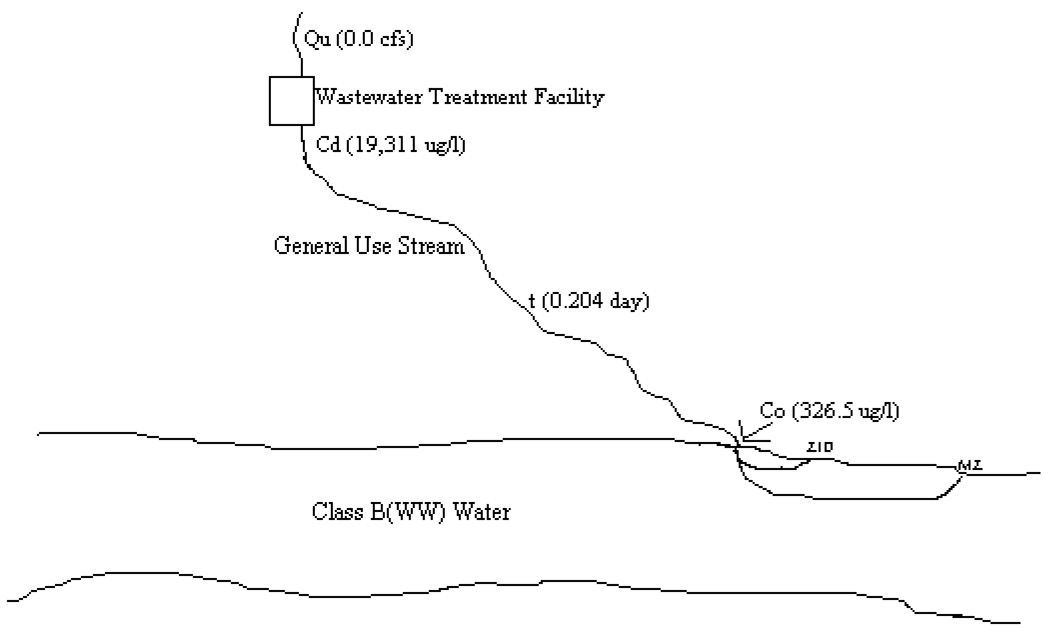
$C_o = WLA_{\text{chronic}}$ = 326.5 µg/l
k = 20 day $^{-1}$
t = 0.204 day (1760 ft. upstream at 0.1 ft./sec.)
t = d/v = 1760/0.1 = 17,600 sec.
17,600 sec./86,400 (sec. in a day) = 0.204 day

$C_d = C_o e^{(kt)}$
$= 326.5e^{(20)(0.204)}$
= 326.5(59.145)
C_d = 19,311 µg/l

TRC Decay Diagram with Zero Background Flow:

Diagram 3 illustrates TRC decay along a general use stream into a Class B(WW) Water.

Diagram 3:



KEY:

Q_u = Background or upstream flow, cfs
C_d = TRC upstream discharge concentration at
time t, ug/l
C_o = WLA TRC concentration, ug/l
k = Decay rate constant, 20 day $^{-1}$

TRC Calculations with Background Flow

Three steps are used to calculate the WLA for a discharger to a general use stream on which a background (or upstream) flow exists. Both the modified TRC Mass Balance and the TRC decay equations are used in this situation. First, the $WLA_{chronic}$ and WLA_{acute} values are calculated using the modified TRC Mass Balance equation for the designated portion of the receiving stream. Second, the WLA $_{chronic\ and\ acute}$ for ADW flow and the WLA $_{chronic\ and\ acute}$ for AWW flow are used in the TRC decay equation to calculate the allowable WLA just downstream of the outfall in the general reach. Finally, the actual WLAs for the outfall are calculated using the modified TRC mass balance equation and the upstream flow and concentration. The overall situation for this type of WLA is shown in the TRC Decay with Background Flow Diagram Examples (Diagrams 4,5,6, and 7).

First Step:

The modified TRC mass balance equation in designated water:

$$C_bQ_b + C_oQ_o = C_s(Q_b + Q_o) + 300\ C_o \qquad (9)$$

WLA $_{chronic}$ Calculation with Background Flow Example (using the MZ):

(This calculation must be done for both ADW and AWW flows.)

where:

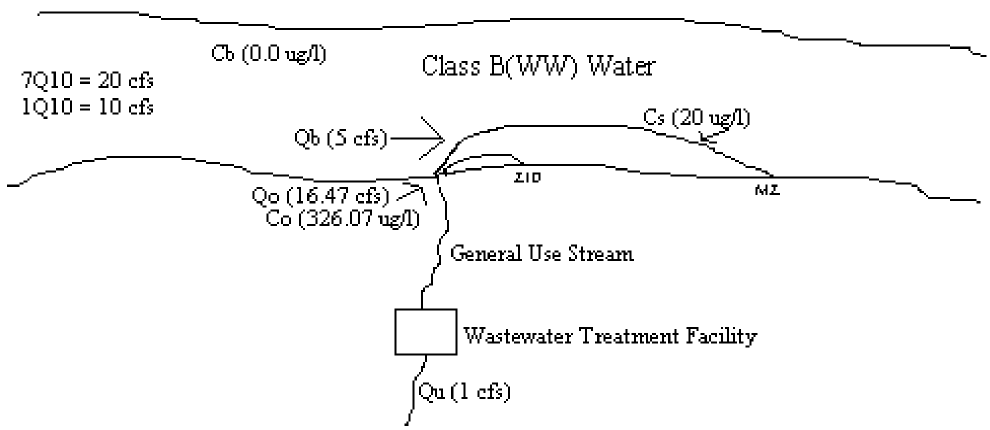
using $7Q_{10} = 20$ cfs
$C_b = 0.0\ \mu g/l$
$Q_b = ¼(7Q_{10}) = 20/4 = 5$ cfs
$Q_o = \Sigma(Q_D + Q_u)$
Q_D = Discharge flow = 10 mgd (15.47 cfs)
Q_u = Background or upstream flow (1 cfs)
$Q_o = \Sigma(15.47 + 1)$
$Q_o = 16.47$ cfs
$C_s = 20\ \mu g/l$ chronic

$C_bQ_b + C_oQ_o = C_s(Q_b + Q_o) + 300\ Q_o$
$(0.0)5 + C_o(16.47) = 20(5 + 16.47) + 300\ (16.47)$
$0 + C_o(16.47) = 20(21.47) + 300\ (16.47)$
$C_o = \dfrac{20(21.47)}{16.47} + 300$
$C_o = 326.07\ \mu g/l$ WLA $_{chronic}$

WLA $_{chronic}$ Diagram with Background Flow:

Diagram 4 illustrates a discharge to a general use stream that discharges into a designated stream on which a background (or upstream) flow exists. The following diagram illustrates the previous WLA $_{chronic}$ Calculation with Background Flow Example.

Diagram 4:



KEY:

$7Q_{10}$ = 20 cfs
$1Q_{10}$ = 10 cfs
C_b = Background TRC concentration, ug/l
Q_b = Stream flow in MZ, cfs
Q_o = Sum of discharge flow and background flow, cfs
C_s = Water quality standard concentration in the MZ, µg/l

WLA $_{acute}$ Calculation with Background Flow Example (using the ZID):

(This calculation must be done for both ADW and AWW flows.)

where:

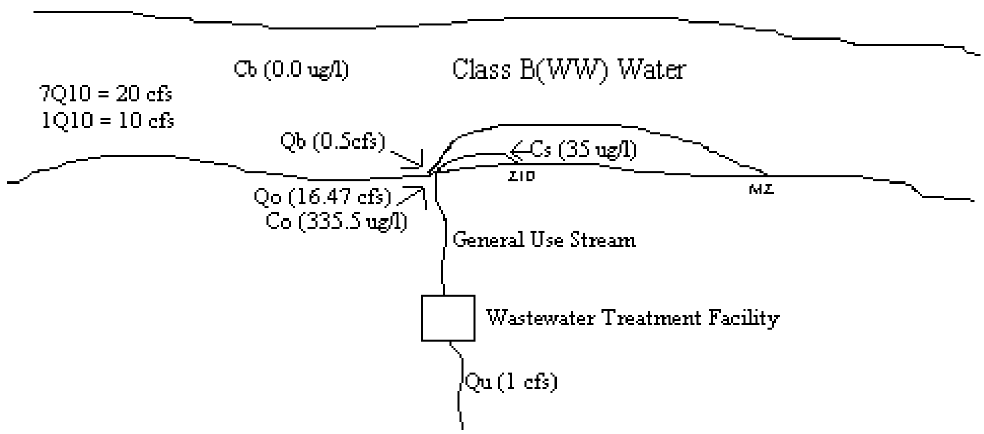
using $1Q_{10}$ = 10 cfs
$C_b = 0.0$ µg/l
$Q_b = 1/40(1Q_{10}) = 10/40 = 0.25$ cfs
$Q_o = \Sigma(Q_D + Q_u)$
Q_D = Discharge flow = 10mgd (15.47 cfs)
Q_u = Background or upstream flow (1 cfs)
$Q_o = \Sigma(15.47 + 1)$
$Q_o = 16.47$ cfs
$C_s = 35$ µg/l acute

$C_bQ_b + C_oQ_o = C_s(Q_b + Q_o) + 300\ Q_o$
$(0.0)0.25 + C_o(16.47) = 35(0.25 + 16.47) + 300\ Q_o$
$0 + C_o(16.47) = 35(16.72) + 300\ Q_o$
$C_o = \frac{35(16.72)}{16.47} + 300$
$C_o = 335.5$ µg/l WLA $_{acute}$

WLA $_{acute}$ Diagram with Background Flow:

Diagram 5 illustrates a discharger to a general use stream that discharges into a designated stream on which a background (or upstream) flow exists. The following diagram illustrates the previous WLA $_{acute}$ Calculation with Background Flow Example.

Diagram 5:



KEY:

$7Q_{10}$ = 20 cfs
$1Q_{10}$ = 10 cfs
C_b = Background TRC concentration, ug/l
Q_b = Stream flow in ZID, cfs
Q_o = Sum of discharge flow and background flow, cfs
C_s = Water quality standard concentration in the ZID,

Second Step:

The WLA $_{chronic\ or\ acute}$ for ADW flow and WLA $_{chronic\ or\ acute}$ for AWW flow from the above step are used in the TRC decay equation. For this example, the more stringent of the

WLA $_{chronic\ or\ acute}$ is the WLA $_{chronic}$ value of 326.07 µg/l. The TRC decay over time "t" is used to calculate the upstream concentration (C_o). The following TRC decay equation for an upstream general waterway with background flow is used for solving for C_{db}.

$$C_{db} = C_o e^{(kt)} \tag{10}$$

where:

C_{db} = TRC upstream discharge concentration at time t, µg/l considering background flow (just below outfall)

C_o = WLA TRC upstream concentration, µg/l

k = Decay rate constant, day $^{-1}$

t = Time of travel in modeled reach, day

TRC Decay for Upstream General Waterway with Background Flow Example:

where:

$C_o = WLA_{chronic} = 326.07$ µg/l

$k = 20$ day^{-1}

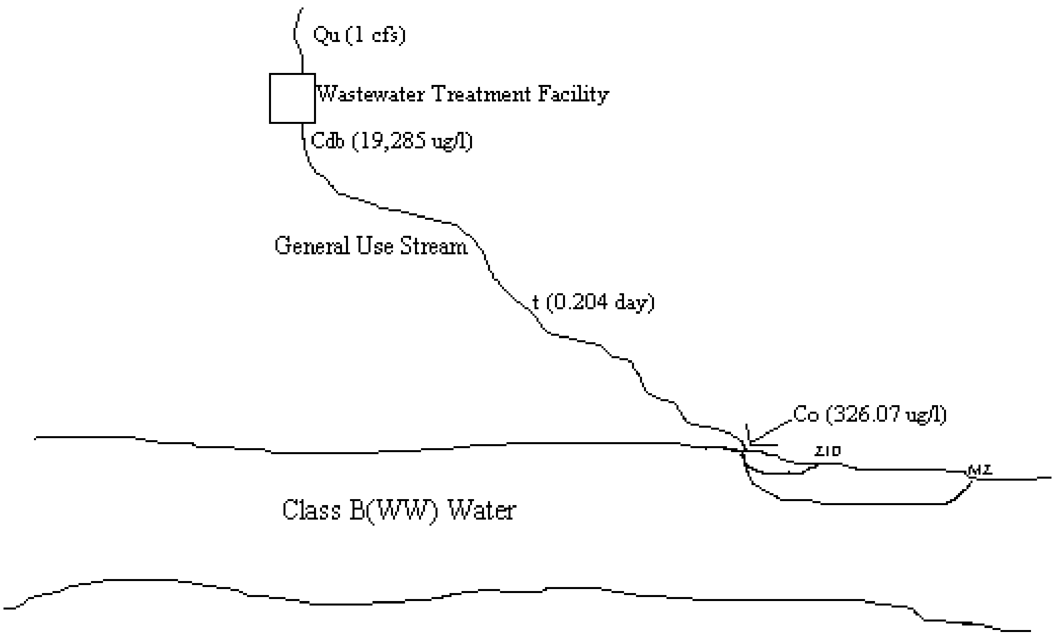
$t = 0.204$ day

$$C_{db} = C_o e^{(kt)}$$
$$= 326.07e^{(20)(0.204)}$$
$$= 326.07(59.145)$$
$$C_{db} = 19{,}285 \text{ µg/l}$$

TRC Decay Diagram with Background Flow:

Diagram 6 illustrates TRC decay along a general use stream that discharges into a Class B(WW) water with a background flow.

Diagram 6:



KEY:

Q_u = Background or upstream flow, cfs
C_{db} = TRC upstream discharge concentration at
time t, ug/l (just below outfall)
C_o = WLA TRC concentration, ug/l
k = Decay rate constant, 20 day $^{-1}$

Third Step:

The discharge flow, upstream TRC concentration, upstream flow in the general reach, and the calculated C_{db} from above will be used in the basic mass balance equation to calculate the amount of TRC for the outfall. In the mass balance equation the effluent concentration (WLA) is noted as C_d.

$$C_uQ_u + C_dQ_d = C_{db}(Q_u + Q_d) \qquad (11)$$

where:

C_u = Background TRC concentration in General Use stream, µg/l
Q_u = Background or upstream flow in the general reach, cfs
Q_d = Effluent flow, cfs
C_{db} = Discharge TRC concentration, µg/l considering background flow
C_d = TRC discharge (outfall) concentration at time "t", µg/l

TRC Mass Balance Equation at Outfall Location Calculation Example:

where:

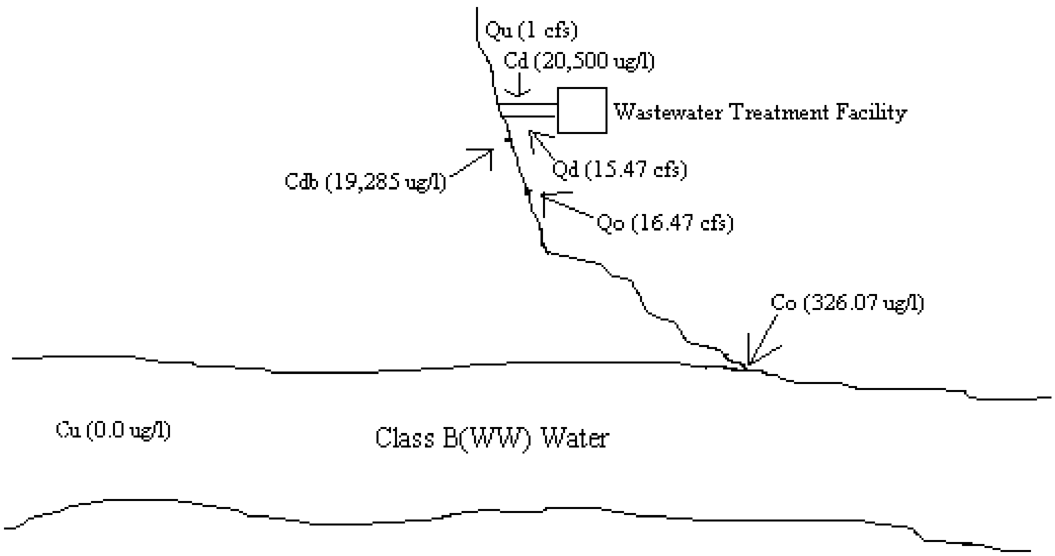
C_u = 0.0 µg/l
Q_u = 1 cfs
Q_d = 10 mgd (15.47cfs)
C_{db} = 19,285 µg/l

$C_uQ_u + C_dQ_d = C_{db}(Q_u + Q_d)$
$(0.0)1 + C_d(15.47) = 19,285(1 + 15.47)$
$0 + C_d(15.47) = 19,285(16.47)$
$C_d = \dfrac{19,285(16.47)}{15.47}$
C_d = 20,500 µg/l (20.5 mg/l) TRC discharge (outfall) concentration at time 't"

TRC Mass Balance Equation Diagram at Outfall Location:

Diagram 7 illustrates the amount of TRC WLA for the outfall. The following diagram illustrates the previous mass balance equation.

Diagram 7:



KEY:

Q_u = Background or upstream flow, cfs
C_d = TRC discharge (outfall) concentration at time t, ug/l
Q_d = Effluent flow, cfs
C_{db} = Discharge TRC concentration, ug/l considering background flow
Q_o = Sum of discharge flow and background or upstream flow, cfs
C_u = Background TRC concentration in Class B stream.

E. Bacteria: *Escherichia coli* (*E. coli*) will be the indicator for bacteria. *E. coli* effluent limits will be calculated for any wastewater treatment facility discharging directly into or impacting a Class A water. "Waters which are designated Class "A1", "A2", or "A3" in subrule 61.3(5) are to be protected for primary contact, secondary contact, and children's recreational uses" (Chapter 61.3(3)a). For Wasteload Allocations (WLAs) calculated for dischargers to waters designated one of the Class A uses, both the geometric mean and the sample maximum criteria are to be met at the end-of-pipe. The water quality-based effluent limits are established by using both the geometric mean and the sample maximum criteria as the end-of pipe wasteload allocation (WLA). Refer to the Bacteria Criteria Table for the geometric mean and the sample maximum, which are set as the WLA. The geometric mean WLA becomes the average water quality-based effluent limit and the sample maximum becomes the maximum water quality-based effluent limit.

When there is a discharge to a non-Class A water which enters one of the designated Class A waters then *E. coli* decay takes place. An *E. coli* decay equation is used for the geometric mean and the sample maximum to project the amount of *E. coli* loss along the non-Class A stream reach. With or without background flow the geometric mean based bacteria WLA becomes the average water quality-based effluent limit and correspondingly the sample maximum becomes the maximum water quality-based effluent limit.

"The *Escherichia coli* (*E. coli*) content shall not exceed the levels noted in the Bacteria Criteria Table when the Class "A1", "A2", or "A3" uses can reasonably be expected to occur" (Chapter 61.3(3)a(1)).

"The *Escherichia coli* (*E. coli*) content of water which enters a sinkhole or losing stream segment, regardless of the waterbody's designated use, shall not exceed a Geometric Mean value of 126 organisms/100 ml or a sample maximum value of 235 organisms/100 ml. No new wastewater discharges will be allowed on watercourses which directly or indirectly enter sinkholes or losing stream segments" (Chapter 61.3(2)h). The Bacteria Criteria Table is as follows:

Bacteria Criteria Table (organisms/100 ml of water)

Use	**Geometric Mean**	**Sample Maximum**
Class A1		
3/15 –11/15	126	235
11/16 –3/14	Does not apply	Does not apply

Class A2 (Only)		
3/15 –11/15	630	2880
11/16 –3/14	Does not apply	Does not apply
Class A2 and B(CW) or HQ		
Year Round	630	2880
Class A3		
3/15 –11/15	126	235
11/16 –3/14	Does not apply	Does not apply

Class A1 – Primary Contact Recreational Use, Class A2 - Secondary Contact Recreational Use, Class A3 – Children's Recreational Use

When a water body is designated for more than one of the recreational uses, the most stringent criteria for the appropriate season shall apply.

<u>Background Levels</u>

To assure compliance with Chapter 61.3(3)a(1), all calculations will incorporate background *E.coli* levels associated with non-runoff periods. Available STORET data will be used to determine the background levels (the 50th percentile value of all non-runoff influenced data points at the sampling site.) For some streams there may not be enough data to provide valid numbers. In these cases, data from a similar stream having similar upstream pollution sources may be used.

<u>Calculations</u>

Wasteload allocations (WLAs) are calculated to determine effluent limits by hand calculations and first order decay of *E. coli*. The Iowa Department of Natural Resources (IDNR) has a spreadsheet available on Microsoft Excel to solve for the maximum discharge concentration when *E.coli* decay is applicable. Background flow, defined as the sum of all upstream flows and any incremental flows along the modeled reach, can be added at one of the three reach entries on the Microsoft Excel spreadsheet. The incremental flows should be included at the appropriate distance below the discharge.

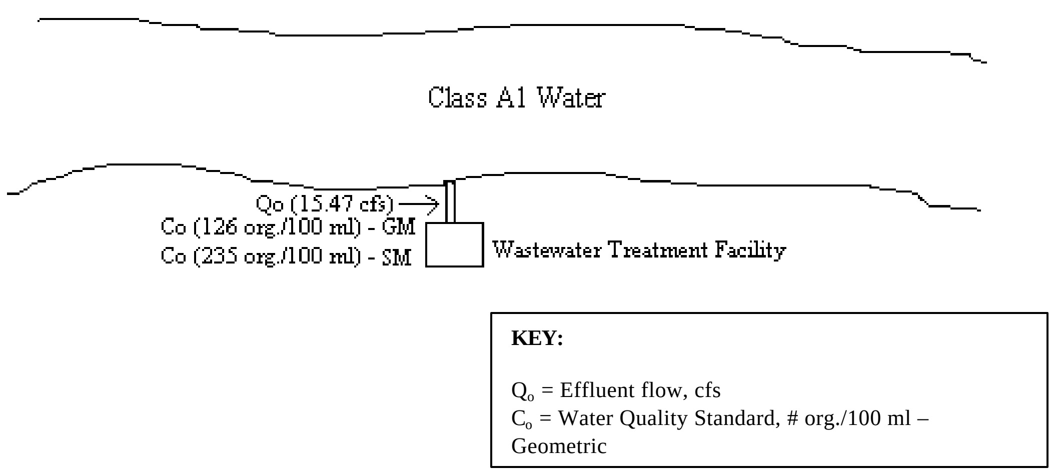
<u>Discharge directly to any of the Class A Waters</u>

Effluent limits are found by using both the geometric mean and the sample maximum criteria as the end-of-pipe wasteload allocation (WLA). Refer to the Bacteria Criteria Table for the geometric mean and the sample maximum, which are set as the WLA. The geometric mean WLA becomes the average water quality-based effluent limit and the sample maximum becomes the maximum water quality-based effluent limit.

Diagram for Shoreline Discharge Directly into a Class A1 Water:

Diagram 8 illustrates a shoreline discharge directly to a Class A1 Water. The following diagram illustrates the geometric mean WLA and the sample maximum WLA are the average and maximum water quality-based effluent limits.

Diagram 8:



E. coli Decay:

The *E. coli* decay equation is used when there is a discharge to a non-Class A water (having zero flow). The decay equation will project the amount of *E. coli* loss along the non-Class A stream reach. The decay model uses a traditional relationship in which time of travel in the non-Class A designated stream reach is incorporated into the calculations. The model formulated in the EPA publication *"Rates, Constants and Kinetics Formulation in Surface Water Quality Modeling"* (Second Edition), June 1985, is used for *E. coli* decay. The resulting WLA is more relaxed than the WLA calculated in the direct discharge to the designated reach. The following *E. coli* equation is used when there is zero background flow in the non-Class A water, solving for C_d.

$$C_d = C_o e^{(kt)} \qquad (12)$$

where:

C_d = *E. coli* discharge concentration,

org./100 ml – Geometric Mean (GM)
and Sample Maximum (SM)

C_o = Water Quality Standard, # org./100 ml – Geometric Mean (GM) and Sample Maximum (SM)

k = Decay rate constant, day $^{-1}$

t = Time of travel in modeled reach, day

The *E. coli* criteria value from the water quality standard in the designated segment must be used in the above equation.

E. coli Decay with Zero Background Flow Example:

where:

C_o = 126 org./100 ml = Geometric Mean WLA
C_o = 235 org./100 ml = Sample maximum WLA
k = 5.28 day $^{-1}$
t = 0.204 day (1760 ft. upstream at 0.1 ft./sec.
t= d/v = 1760/0.1 = 17,600 sec.
17,600 sec./86,400 (sec. in a day) = 0.204 day

Decay for the Geometric Mean:

$C_d = C_o e^{(kt)}$
$= 126e^{(5.28)(0.204)}$
= 126(2.936)
C_d = 370 org./100 ml – GM

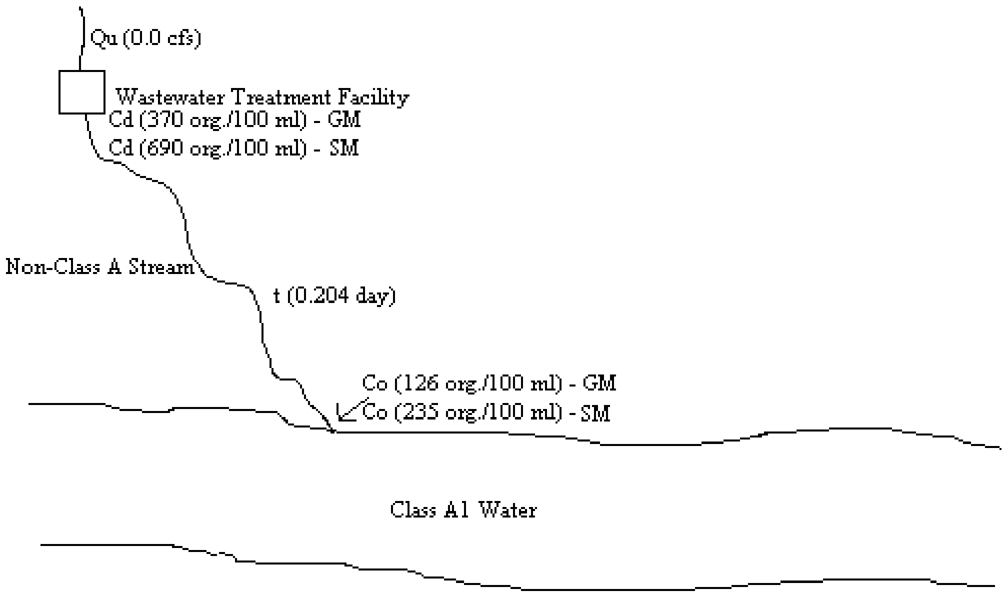
Decay for the Sample Maximum:

$C_d = C_o e^{(kt)}$
$= 235e^{(5.28)(0.204)}$
= 235(2.936)
C_d = 690 org./100 ml - SM

E. coli Decay Diagram with Zero Background Flow:

Diagram 9 illustrates *E. coli* decay along a non-Class A stream into a Class A1 water. The decay WLA (370 org./100 ml) calculated for the geometric mean becomes the average water quality-based effluent limit and the decay WLA (690 org./100 ml) calculated for the sample maximum becomes the maximum water quality-based effluent limit.

Diagram 9:



Key:

Q_u = Background or upstream flow, cfs
C_d = *E. coli* discharge concentration,
org./100 ml – Geometric Mean (GM)
and Sample Maximum (SM)
C_o = Water Quality Standard, # org./100 ml – Geometric
Mean (GM) and Sample Maximum (SM)
k = Decay rate constant. 5.28 day $^{-1}$

***E. coli* Calculations with Background Flow**

Three steps are used to calculate the *E. coli* WLA's for a discharger to a non-Class A stream on which a background (or upstream) flow exists. Both the Water Quality Standard (refer to Bacteria Criteria Table) and the *E. coli* decay equations are used in this situation. The first is to determine the designation of the water, either designated Class A1, A2, or A3. Second, the WLA value is used in the *E. coli* decay equation to calculate the allowable WLA just downstream of the outfall in the non-Class A reach. Finally, the actual WLA for the outfall is calculated using the mass balance equation and the upstream flow and concentration. The overall situation for this type of WLA is shown in the *E. coli* with Background Flow Diagram Examples (Diagrams 10, 11, and 12).

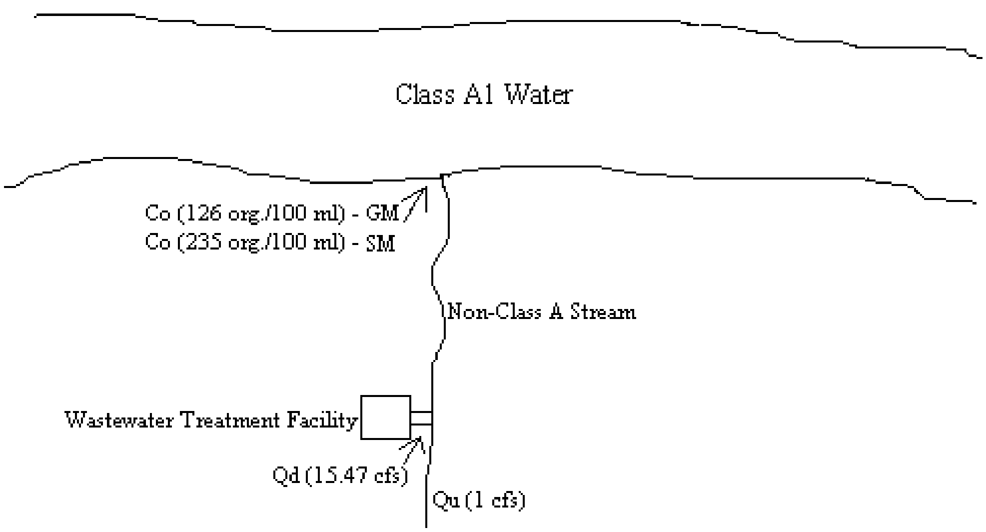
First Step:

The first step is to determine the designation of the water, either designated Class A1, A2, or A3. The geometric mean and the sample maximum are set as the WLA to be met at the mouth of the unnamed creek.

E. coli Diagram with Background Flow to a Class A1 Water:

Diagram 10 illustrates a shoreline discharge to a non-Class A stream on which a background (or upstream) flow exists. In this example the WLA's are C_o = 126 org./100 ml = geometric mean and C_o = 235 org./100 ml = sample maximum.

Diagram 10:



KEY:

Q_u = Background or upstream flow, cfs
Q_d = Discharge flow, cfs
C_o = Water Quality Standard, # org./100 ml – Geometric

Second Step:

The WLA value from the above step is used in the *E. coli* decay equation. The *E. coli* decay over time 't' is used to calculate the upstream concentration (C_o). The following *E. coli* decay equation for an upstream general waterway with background flow is used for solving for C_{db}.

$$C_{db} = C_o e^{(kt)} \tag{13}$$

where:

C_{db} = *E. coli* concentration at time t, # org./100 ml (just below outfall) – Geometric Mean (GM) and Sample Maximum (SM)
C_o = *E. coli* Water Quality Standard, # org./100 ml – Geometric Mean (GM) and Sample Maximum (SM)
k = Decay rate constant, day $^{-1}$
t = Time of travel in modeled reach, day

E. coli Decay for Upstream Non-Class A Stream with Background Flow Example, Solving for C_{db}:

where:

C_o = 126 org./100 ml = Geometric Mean WLA
C_o = 235 org./100 ml = Sample Maximum WLA
$k = 5.28\ \text{day}^{-1}$
$t = 0.204$ day

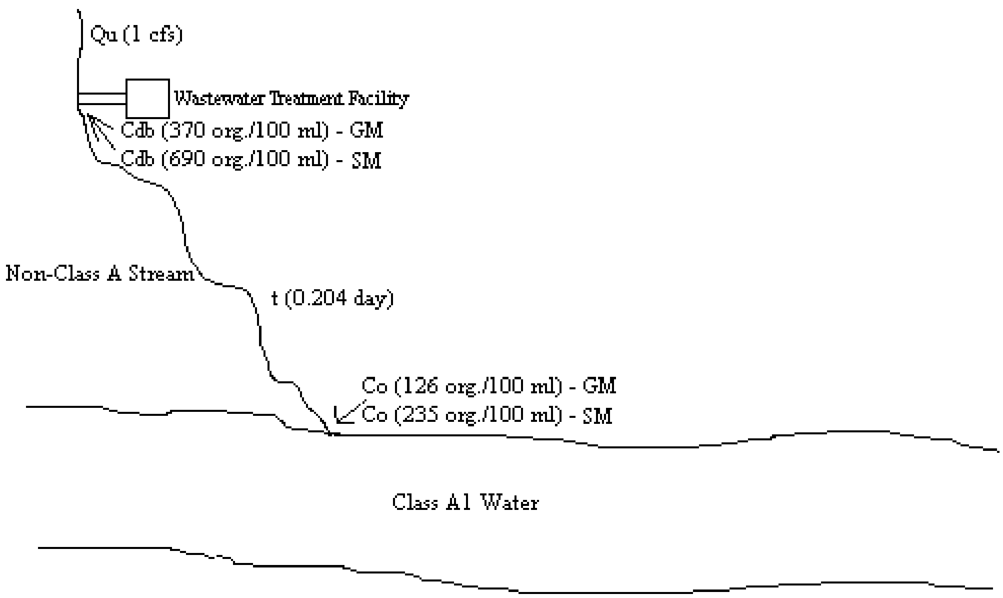
<u>Decay for the Geometric Mean:</u>
$C_{db} = C_o e^{(kt)}$
$= 126e^{(5.28)(0.204)}$
$= 126(2.936)$
C_{db} = 370 org./100 ml - GM

<u>Decay for the Sample Maximum</u>
$C_{db} = C_o e^{(kt)}$
$= 235e^{(5.28)(0.204)}$
$= 235(2.936)$
C_{db} = 690 org./100 ml – SM

E. coli Decay Diagram with Background Flow:

Diagram 11 illustrates *E. coli* decay along a non-Class A stream into a Class A1 water with a background flow.

Diagram 11:



KEY:

Q_u = Background or upstream flow, cfs
C_{db} = *E. coli* concentration at time t, # org./100 ml (just below outfall) – Geometric Mean (GM) and Sample Maximum (SM)
C_o = Water Quality Standard, # org./100 ml – Geometric Mean (GM) and Sample Maximum (SM)
k = Decay rate constant, 5.28 day $^{-1}$

Third Step:

The discharge flow, upstream *E. coli* concentration, upstream flow, and the calculated C_{db} from above will be used in the mass balance equation to calculate the amount of *E. coli* for the outfall. In the following mass balance equation, the effluent concentration (WLA) is noted as C_d.

$$C_uQ_u + C_dQ_d = C_{db}(Q_u + Q_d) \quad (14)$$

where:

C_u = Background *E. coli* concentration, # org./100 ml
Q_u = Background or upstream flow, cfs
Q_d = Effluent flow, cfs
C_{db} = *E. coli* concentration at time t, # org./100 ml (just below outfall) – Geometric Mean (GM) and Sample Maximum (SM)
C_d = *E. coli* discharge concentration, # org./100 ml – Geometric Mean (GM) and Sample Maximum (SM)

Mass Balance Equation for E. coli at Outfall Location Calculation Example:

where:

<u>The Geometric Mean:</u>
C_u = 75 org./100 ml
Q_u = 1 cfs
Q_d = 10 mgd (15.47)
C_{db} = 370 org./100 ml - GM

$C_uQ_u + C_dQ_d = C_{db}(Q_u + Q_d)$
$(75)1 + C_d(15.47) = 370(1 + 15.47)$
$75 + C_d(15.47) = 370(16.47)$
$C_d(15.47) = 6094 – 75$
$C_d = \frac{6019}{15.47}$
C_d = 389 org./100 ml *E.coli* discharge concentration - GM

<u>The Sample Maximum:</u>
C_u = 75 org./100 ml
Q_u = 1 cfs
Q_d = 10 mgd (15.47 cfs)
C_{db} = 690 org./100 ml - SM

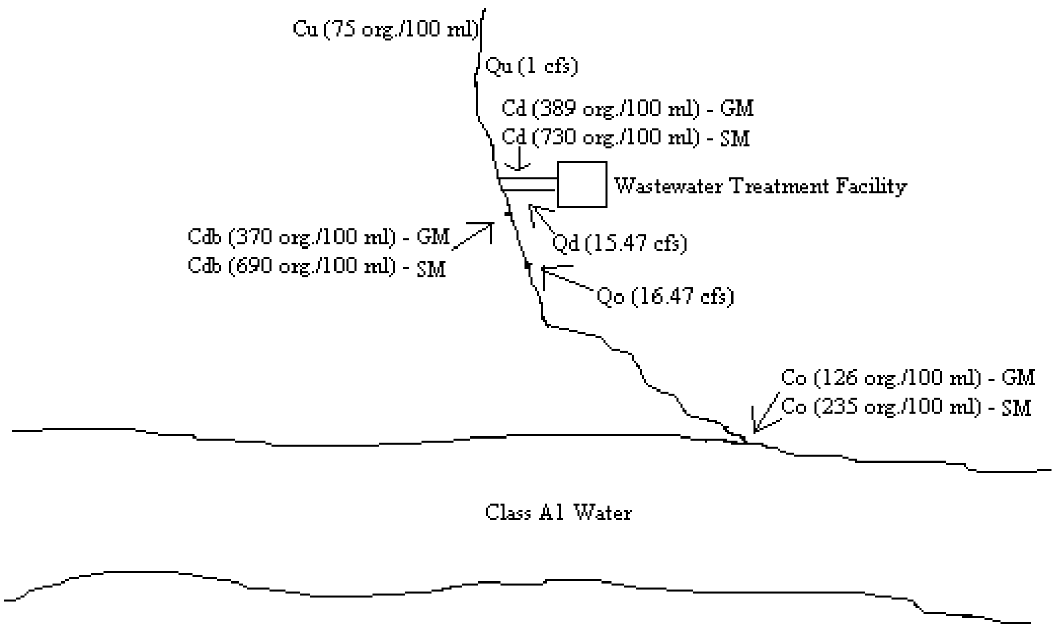
$C_uQ_u + C_dQ_d = C_{db}(Q_u + Q_d)$
$(75)1 + C_d(15.47) = 690(1 + 15.47)$
$75 + C_d(15.47) = 690(16.47)$
$C_d(15.47) = 11364 – 75$
$C_d = \frac{11289}{15.47}$
C_d = 730 org./100 ml *E.coli* discharge concentration - SM

E. coli Mass Balance Equation Diagram of Outfall Location:

Diagram 12 illustrates the amount of *E. coli* for the outfall. The following diagram illustrates the previous mass balance equation. The geometric mean WLA (C_d = 389 org./100 ml) becomes the average water quality-based effluent limit and the Sample maximum WLA

(C_d = 730 org./100 ml) becomes the maximum water quality-based effluent limit. These water quality-based effluent limits are determined by following the previous three steps (pages 35-40).

Diagram 12:



KEY:

Q_u = Background or upstream flow, cfs
C_d = *E. coli* discharge concentration, # org./100 ml - Geometric
Mean (GM) and Sample Maximum (SM)
Q_d = Effluent flow, cfs
C_{db} = *E. coli* concentration at time t, # org./100 ml
(just below outfall) - Geometric Mean (GM)
and Sample Maximum (SM)
Q_o = Sum of discharge flow and background or upstream
flow, cfs

1. **F. Cation and Anion Guideline Values for Livestock Watering:** The protection of the defined uses requires application of the ion guidelines as 'end-of-pipe' limits in general waters. In designated waters, the guideline values would be met at the boundary of the mixing zone.

Recommended Water Quality Guidelines
for
Protecting Defined Uses

Ions	Recommended Guidelines Values* (mg/l)
Calcium	1000
Chloride	1500
Magnesium	800
Sodium	800
Sulfate	2000
Nitrate+Nitrite-N	100

* Based on the guidelines for livestock watering.

G. General Criteria for Streams: The water quality standards specifically mention seven criteria that apply to all surface waters Chapter 61.3(2) (commonly referred to as "free from" criteria). These criteria are also considered in setting the wasteload allocation (WLA) for a discharge to streams that are included in one or more on the six designated uses. In waters not included in any of the six designated uses, these seven criteria must still be met. No specific WLA procedures have been established for four of the five "free from" general use criteria. Of particular importance is setting WLAs is the criterion (61.3(2)d), which states that waters must be free from of any substance which is **acutely** toxic to human, animal or plant life. Only the "free from" acutely toxic conditions has an established procedure. This procedure is described in the following discussion.

The nature of streams covered by the seven general criteria varies widely. The stream being evaluated may be a perennial stream or an intermittently flowing channelized drainage ditch. Each flow regime and habitat has its own resident species present and the specific acutely toxic levels can only be determined by a case by case evaluation. Some of the items that are considered in an evaluation are the applicable flow regime, resident species present, and acutely toxic levels associated with those species.

In order that acutely toxic conditions are not exceeded in the stream, the concept of establishing a no-effect level or LC_0 is introduced. The LC_0 is determined by calculating the value of ½ the 96 hour LC_{50} for the most sensitive resident species.

A design low flow is defined as that stream flow regime at which the critical resident species of the aquatic organisms, which may reside in the stream, will be present. The establishment of a design low flow for a general stream is done using a similar approach to set design low flows for Class B streams. The intermittent nature of many general streams will not support a viable aquatic community. Therefore, a case by case determination of the design low flow regime should be made based on: the amount of discharge from wastewater treatment facilities, the reoccurrence of design low flow, and the design low stream flow necessary to support the normally occurring aquatic species and the season. Typically, a flow regime of 1 to 2 cfs would support the resident aquatic species during summer and winter periods.

The evaluation of resident aquatic species should only include species found during the design low flow periods, not those species found during spawning (i.e. higher flow) periods when adequate dilution occurs. Once the resident species are established (or projected), the LC_0 or
96 hour LC_{50} values are obtained for the species from the EPA document, “Ambient Water Quality Criteria for (the toxic of concern)”, Table 3. The most sensitive specie and associated concentration will be used as the water quality criterion in the following mass balance equation.

$$C_bQ_b + C_oQ_o = \frac{C_s}{2}(Q_b + Q_o) \qquad (15)$$

where:

C_b = Background pollutant concentration, µg/l
Q_b = Design low stream flow in the general classified segment (about the outfall), cfs
Q_o = Effluent flow, cfs
C_s = Genus Mean Acute Value for most sensitive species in receiving stream, µg/l
C_o = WLA for the pollutant of concern concentration, µg/l

Solve the equation for C_o. This value will be compared to the acute wasteload allocation calculated in the previous Toxic sections (i.e. ammonia nitrogen, total residual chlorine, etc.). The most stringent of the wasteload allocations will be used in the Permit Derivation Procedure section (pages 55-56). In the following example, the C_o value will be compared to the total residual chlorine WLA acute calculation. Two mass balance equations will be calculated, one for a general use stream with zero background flow and one for a general use stream with a background flow.

Example of WLA – Protection of General Use Stream with Zero Background Flow:

The following WLA example will solve for the pollutant chlorine and will use the species fathead minnow (Pimephales promelas) which is a common species found in general use streams and is a common test species. The genus mean acute value of the fathead minnow is 105.2 µg/l (Ambient Water Quality Criteria for Chlorine - 1984, Table 3, page 34). The general use stream has zero background flow in this mass balance equation example.

Chlorine Calculation with Zero Background Flow Example:

where:

C_b = 0.0 µg/l
Q_b = 0.0 cfs
Q_o = 10 mgd (15.47 cfs)
C_s = 105.2 µg/l

$$C_bQ_b + C_oQ_o = \frac{C_s(Q_b + Q_o)}{2}$$

$$(0)0 + C_o(15.47) = \frac{105.2(0 + 15.47)}{2}$$

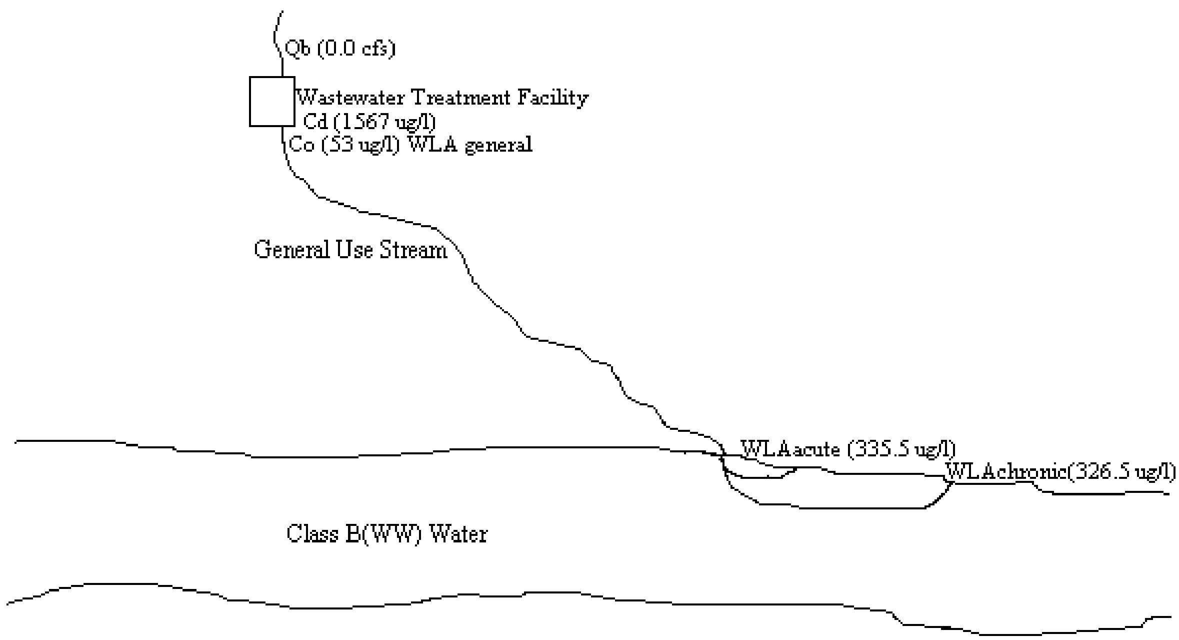
$$C_o = \frac{105.2}{2}$$

C_o = 53 µg/l WLA

Chlorine WLA Diagram with Zero Background Flow:

Diagram 13 illustrates a chlorine WLA in a general use stream (labeled $WLA_{general}$) with a zero background flow.

Diagram 13:



KEY:

Q_b = Design low stream flow in the general classified
segment (above the outfall), cfs
C_o = $WLA_{general}$ for chlorine, ug/l

Note: The WLA_{acute} and $WLA_{chronic}$ in the above diagram are the Total Residual Chlorine (TRC) WLA_{acute} and $WLA_{chronic}$ with shoreline discharge that are shown in previous examples (pages 20 and 19, respectively). C_d is $WLA_{chronic}$ decayed to the outfall (see pages 20-22).

Example chlorine $WLA_{general}$ = 53 µg/l

Example $WLA_{chronic}$ decayed to outfall = 1,567 µg/l

The more stringent of the acute WLAs and the $WLA_{general}$ is the TRC WLA of 53 µg/l. The Permit Derivation Procedure section (pages 55-56) will use these two WLAs.

<u>Example of WLA – Protection of General Use Stream with Background Flow:</u>

The following WLA example will solve for the pollutant chlorine and will use the species fathead minnow (<u>Pimephales promelas)</u> which is a common aquatic species. The genus mean acute value (µg/l) of the fathead minnow is 105.2 µg/l (Ambient Water Quality Criteria for

Chlorine – 1984, Table 3, page 34). The general use stream has a background flow in this mass balance equation example.

Chlorine Calculation with Background Flow Example:

where:

$C_b = 0.0$ µg/l
$Q_b = 1$ cfs
$Q_o = 10$ mgd (15.47 cfs)
$C_s = 105.2$ µg/l

$$C_bQ_b + C_o\,Q_o = \frac{C_s(Q_b + Q_o)}{2}$$

$$(0)1 + Co(15.47) = \frac{105.2(1 + 15.47)}{2}$$

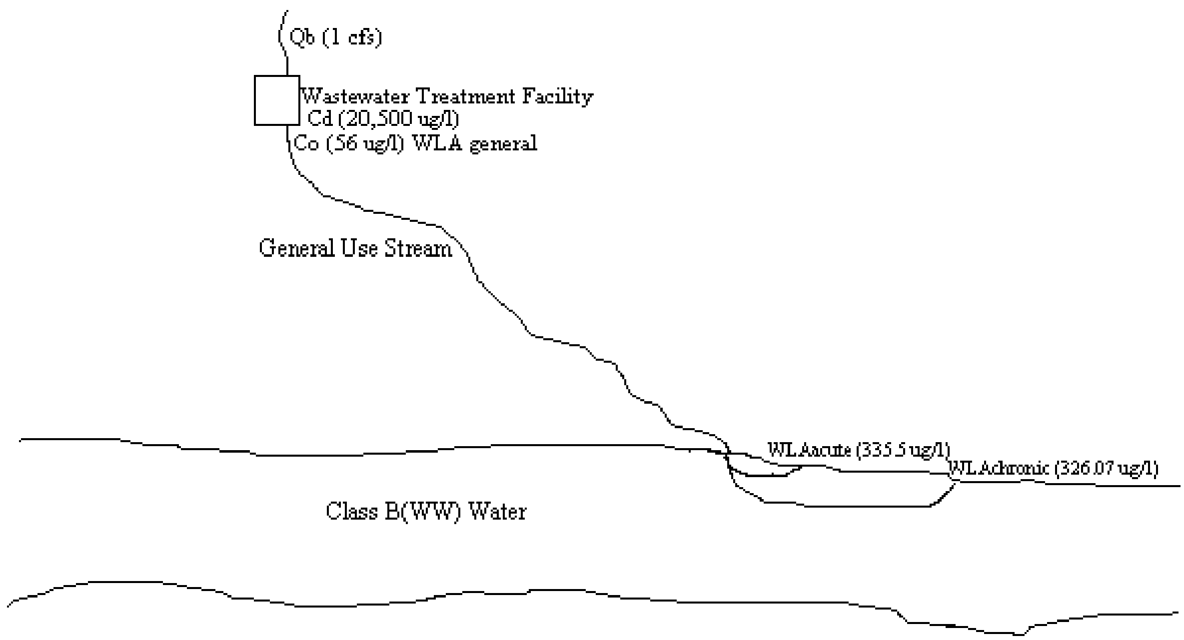
$$Co = \frac{53(16.47)}{15.47}$$

$Co = 56$ µg/l

Chlorine WLA Diagram with Background Flow:

Diagram 14 illustrates a chlorine WLA in a general use stream (labeled $WLA_{general}$) with a background flow.

Diagram 14:



KEY:

Q_b = Design low stream flow in the general classified
segment (above the outfall), cfs

C_o = $WLA_{general}$ for chlorine, ug/l

Note: The WLA_{acute} and $WLA_{chronic}$ in the above diagram is the TRC WLA_{acute} and $WLA_{chronic}$ with background flow that is shown in previous examples (pages 22-26). C_d is $WLA_{chronic}$ decayed and diluted to the outfall (see page 28).

Example chlorine WLA = 56 µg/l

Example $WLA_{chronic}$ decayed and diluted to outfall = 20,500 µg/l

The more stringent of these two WLAs is the TRC WLA of 56 µg/l. The Permit Derivation Procedure section (pages 55-56) will use these two WLAs.

FLOW VARIABLE LIMITATIONS PROCEDURES

Purpose

To provide wastewater treatment facilities the option of discharging higher concentrations or loadings of ammonia or other water quality-based parameters as the stream flows increase. These higher levels of pollutants will not violate water quality standards.

Procedure

This procedure will provide explanation on which treatment facilities could be considered for flow variable ammonia limits and the methodology to calculate specific limitations. The procedure for ammonia limits was selected due to its frequent usage. The procedure for other pollutants, such as temperature, toxics, and TDS would parallel that of ammonia.

This procedure will consider aerated lagoons and mechanical facilities, which are designed and constructed to remove ammonia nitrogen. The facility must demonstrate to the Iowa Department of Natural Resources its ability to meet design ammonia effluent limits for the whole year. A mechanical facility has to be built to meet the $30Q_{10}$ and $1Q_{10}$ WLA permit limits because it cannot store wastewater like an aerated lagoon.

The calculations for flow variable ammonia limits are dependent on stream flow. It is important that a stream gauge upstream of the treatment facility be available to provide daily stream flow readings. The gauge should be near to the treatment facility to accurately represent the stream flow at the outfall.

Flow variable limits for ammonia having both an Average and Maximum Limits. There will be 12 different flow variable limits for each month of the year. The flow variable limit will calculate pounds per day per cfs. Because of the potentially wide range of effluent flows, the pounds per day per cfs (#/d/cfs) values should only reflect the available stream flow capacity, not stream flow and effluent flow. Thus the water quality-based permit limits are based on the acute and chronic instream ammonia criteria (less any background ammonia concentration) converted to #/d/cfs. Calculated by:

$$FVM_a = (WQS - Q_u)\ 8.34 * 1 * \%\ \text{of ZID} * 0.646 \tag{16}$$

where:

FVM_a = Flow Variable $Mass_{acute}$, #/d/cfs
WQS = Water Quality Standard, mg/l
Q_u = Upstream concentration or background flow, mg/l
8.34 = Conversion from mg/l to #/day
1 = Represents an example of stream flow, cfs
% of ZID = 2.5
0.646 = Conversion from mgd to cfs

$$FVM_c = (WQS - Q_u)\ 8.34 * 1 * \%\ \text{of MZ} * 0.646 \tag{17}$$

where:

FVM_c = Flow Variable $Mass_{chronic}$, #/d/cfs
WQS = Water Quality Standard, mg/l
Q_u = Upstream concentration or background flow, mg/l
8.34 = Conversion mg/l to #/day
1 = Represents an example of stream flow, cfs
% of MZ = 25
0.646 = Conversion from mgd to cfs

Then the Flow Variable $Mass_{acute}$ and the Flow Variable $Mass_{chronic}$ is converted to Average and Maximum permit limits using the current permit derivation procedure. The more stringent of the wasteload allocation $_{\text{chronic or acute}}$ becomes the average permit limit and the wasteload allocation $_{\text{acute}}$ becomes the Maximum permit limit.

A facility must show compliance at the flow variable mass limits. Use the following equation to calculate the daily flow variable mass loading from the wastewater treatment plant. The facility will need to calculate, at the frequency specified in the permit, the flow variable mass for each day by:

$$\frac{Q_D\ C_D\ 8.34}{Q_R} = \text{Flow Variable Value (\#/d / cfs)} \tag{18}$$

where:

Q_R = River Flow, cfs
Q_D = Discharge Flow, mgd
C_D = Discharge Ammonia Concentration, mg/l

It is important to note that the Discharge Monitoring Report (DMR) will treat the Flow Variable Mass as any other parameter. Monthly average and noting the daily maximum value will be included in the DMR. Compliance will be achieved when the monthly average and daily maximum are less than or equal to the water quality-based flow variable permit limits. The DMR will need to record river flow (in cfs) at the same frequency as the ammonia monitoring along the wastewater treatment plant discharge flow, and ammonia concentrations to facilitate checking the results of this equation. The river flow can be obtained from an upstream gage or from a new gage provided by the City.

MIXING ZONE PROCEDURES

Objective

The objective of this procedure is to provide guidance on the methods to be used in considering a mixing zone (MZ) while determining applicable effluent limitations for a wastewater discharge.

Background

Chapter 61.2(4) of the department's water quality standards defines the MZ of a wastewater discharge. The MZ is located downstream of the zone of initial dilution (ZID). The standards contain specific criteria and considerations, which are to be used in determining the extent and nature of a MZ. The most restrictive of the provisions establishes the MZ dimensions and flow. The following is a summary of the key provisions of the standards, additional policies, and the sequence used in defining the regulatory MZ and ZID.

1. The maximum flow in the MZ for toxic parameters will be set as 25% of the $7Q_{lO}$ for interior streams, Big Sioux River, Des Moines River and 10% of the Mississippi and Missouri Rivers. The maximum flow in the MZ for ammonia is discussed on pages 17-18.

2. The flow in the MZ will be restricted by the natural functions and influences of mixing, which limit how much water can mix with the discharge effectively. These influences can be islands, semi-permanent

sandbars, and manmade obstructions. For larger rivers the WLA calculations will use 25% of the portion of the flow in the main or side channel into which the facility discharges or the MZ travels, where that flow is separated from flow in the other channels of the river by sandbars or islands which have remained in place for more than three years.

3. The length of the MZ may not exceed the most restrictive of the following seven conditions:
   a. The distance to the juncture of two perennial streams.
   b. The distance to a public water supply intake.
   c. The distance to the upstream limits of a heavily used recreational area.
   d. The distance to the middle of a crossover point in a stream where the main current flows from one bank across to the opposite bank.
   e. The distance to another MZ.
   f. A distance of 2000 feet.
   g. The location where the MZ contained the percentages of stream flow noted in one and two above.

4. The length of and flow in the ZID for toxics may not exceed 10% of the MZ values. For ammonia, the length and flow of the ZID is discussed on pages 18-19.

The chronic criteria for toxics and ammonia nitrogen will be met at the boundary of the MZ. The acute criteria for toxics and ammonia nitrogen will be met at the boundary of the ZID. Although not specifically discussed in the standards, the effects of the Biological Oxygen Demand (BOD) are not expected to be observed until after the end of the regulatory MZ. This is because the movement of water through the MZ normally will occur faster than the biological uptake of oxygen due to the BOD.

These two zones will be determined in one of two manners, by actual field measurements at design low stream flow conditions or by use of a dispersion model. It is the goal of the department to obtain all necessary information of these zones from the information submitted in a wastewater treatment facility's NPDES permit application. A field procedure protocol has been developed for a NPDES applicant to obtain actual field data (see Appendix B). Until data is submitted as part of the NPDES permit application, the limited field data obtained at a few sites by EPA, University Hygienic Laboratory, and the department staff and the use of the dispersion model will be the only means to determine these zones.

Calculations

When conditions at the discharge violate model assumptions, the MZ model used by the department staff is a Far Field Plume Model. The model equations use the predicted or observed stream width, average stream depth, average stream velocity, and channel slope to develop a lateral dispersion coefficient and a shear velocity relationship. These are then used to develop a prediction of the MZ size and flow. A copy of the model program on Lotus 123 software is available from the department. Further information on the equations used is shown in Appendix B, Mixing Zone Calculations (pages B). Where data warrants its use, a more complex model using a Fortran code may be used. It also is available from the department. A list of models used by the department in setting wasteload allocations is also available.

THERMAL DISCHARGERS

Numerous thermal dischargers impact Iowa rivers and streams. The significant thermal discharges result from electric power generation facilities and industrial facilities requiring cooling of equipment or process systems. Specific instream temperature changes are noted in the water quality standards along with the requirement that the standards be met beyond the mixing zone. The complex nature of heat transfer and dispersion make accurate predictions of a thermal plume nearly impossible. However, there still is a need to calculate the expected temperature rise and the distance to recover to (near) initial conditions.

Several technical approaches are available to address the thermal impacts. Extensive evaluations have been performed under EPA Effluent Guideline Requirements for Electric Generating Facilities - Part 316(a). The results or findings of these studies will serve as the primary method for staff to evaluate thermal impacts. For locations where 316(a) information is not practical to apply, staff will use the following mathematical approach.

The temperature elevation after the stream and discharge flows have become well mixed is given by the following relationship. (Source: U.S. EPA, Water Quality Assessment, pg. 451, eq. IV-66).

$$\Delta T_{wm} = (Q_p/Q_r)\,(T_e - T_r) \tag{19}$$

where:

ΔT_{wm} = temperature elevation after initial well mixing, °F
Q_p = flow rate of the cooling water, cfs
Q_r = flow rate of river in mixing zone, cfs
T_e = temperature of heated effluent, °F
T_r = temperature of river above discharge, °F

This relationship does not account for the heat losses that occur as the two flows become mixed. For interior streams, the value of ΔT_{wm} should be equal or less than 3°C (5.4°F) as required in the Water Quality Standards.

Procedures are available from the EPA "Water Quality Assessment" document to calculate instream distances from the point of initial mixing until the stream temperature recovers to levels allowed by water quality standards. The mathematical relationships presented in the EPA document have not been verified for Iowa stream and river conditions. Several alternative calculation approaches should be considered along with data generated from Part 316(a) studies. Example distance calculations can be found in the U.S. EPA "Water Quality
Assessment" document on pages 423 to 461.

The mixing zone cross sectional area and volume discussion above also applies to the calculations for thermal dischargers. The reduction of the percent of river area or volume in the mixing zone (below the 25% requirement) for the Mississippi and Missouri Rivers has additional justification when the heated plume influences the highly productive fish habitat areas and identified clam beds often located along the stream bank or near bank areas.

PERMIT DERIVATION PROCEDURE

This section of the Support Document describes the method used to translate a wasteload allocation (WLA) into an NPDES permit limit. The procedures are applied to any discharger in the state (municipal, industrial, or semi-public) for whom a water quality-based permit limit is required. The purpose of these procedures are to provide an effluent limit which will statistically assure that the WLA will not be exceeded due to the variations in facility operation, monitoring and parameter analysis.

Statistical-Based Procedure:

Maximum Daily Limits (MDL) and Average Monthly Limits (AML) will be calculated using the statistical procedure noted in Appendix C, Iowa Permit Derivation Methods (pages C1-C3). The Iowa statistical-based procedure adopts the modified 1991 EPA Technical Support Document (TSD) methodology. For toxics, this procedure will consider the required sampling frequency for each water quality based parameter noted in Chapter 63 of the department rules and any known coefficient of variation (CV) for each parameter. This CV may be based on the individual treatment facility's operations. Where the CV data is lacking, a value of 0.6 will be used. If a wastewater treatment facility selects to increase the monitoring frequency, the corresponding permit limits will be calculated to reflect this increase frequency. For ammonia, the permit limits are derived directly from the acute WLAs and chronic WLAs.

In addition, technology-based requirements must also be met.

SEGMENT ANALYSIS METHODOLOGY

The ability of a stream to maintain an acceptable dissolved oxygen (DO) concentration is an important consideration in determining its capacity to assimilate wastewater discharges. DO is used in the microbial oxidation of organic and certain inorganic matter present in wastewater. Oxygen supplied principally by reaeration from the atmosphere will replace any DO lost through oxidation processes. If, however, the rate of oxygen use exceeds the rate of reaeration, the DO concentration may decrease below minimum allowable standards.

To predict the variation in DO, as well as ammonia concentration in streams, several computer-based mathematical models have been used. The two models presently utilized are the Modified Iowa and the more sophisticated QUAL-II program. Each of these is described later in this chapter. Input data for the models was developed from existing technical information and recent field investigations of selected streams. When sufficient data was not available, conservative assumptions were made that tend to assure a high degree of protection for water quality without imposing unrealistically stringent effluent limitations. Recent water quality sampling has helped to demonstrate the reliability of particular constants and assumptions used and has improved the validity of the models. Available data allows a reasonably accurate prediction of the impact of different wastewater loads or treatment arrangements upon the DO and ammonia concentrations to be performed. The current data also allows for the determination of wastewater discharges that will not result in violation of water quality standards.

THEORY AND METHODOLOGY

Modeling Theory

Dissolved oxygen (DO) concentrations in streams are controlled by many factors including atmospheric reaeration, biochemical oxygen demands (carbonaceous and nitrogenous), algal photosynthesis and respiration, benthal oxygen demands, temperature, and the physical characteristics of the stream. Many of these factors are difficult, if not impossible, to accurately assess. As a result of this difficulty, limitations on the use of these controlling factors are discussed below.

Photosynthesis can produce large quantities of oxygen during the day if algae are present in the stream. Conversely, at night, algal respiration creates an oxygen demand. Research efforts have attempted to fit harmonic functions to this phenomenon, but with limited success. Specific allowance for diurnal fluctuations in oxygen levels is only included in the QUAL-II computer model.

Benthal oxygen demands result from anaerobic decomposition of settled organic material at the bottom of the stream. These reactions release carbonaceous and nitrogenous organic materials that create biochemical oxygen demands. The inclusion of benthal oxygen demands in the QUAL-II model requires extensive field surveys to determine the real extent of sludge deposits within a stream and coefficients that describe the release into the water. Since the impact is minor in most instances and no data are available to accurately describe sludge deposition areas, no special allowance for benthal oxygen demands is included in the Modified Iowa model formulation. However, QUAL-II has provisions for benthic activities, which need sufficient field data to calibrate and verify the rate constants. If field data are not available, default rate constant values can be used.

A complete mathematical model to describe DO concentrations within the stream would include all significant factors. Natural streams cannot presently be expressed mathematically with absolute certainty, but reasonably accurate predictions can be made through realistic assumptions concerning the reaeration phenomenon and deoxygenation caused by carbonaceous and nitrogenous biochemical oxygen demands (BOD). Specific values obtained in detailed field investigations from other locations, with particular emphasis placed upon data collected in Iowa, provide the only basis for defining ranges of coefficient values being incorporated in the water quality models today. The continued effort towards the collection of water quality data at low flow conditions will aid in defining the above coefficient ranges used in the future.

Nitrogenous BOD is due to the oxidation of ammonia to nitrates by certain species of bacteria. This oxidation process is called nitrification. Nitrification is a two-step process whereby a specific bacterial species oxidizes ammonia to nitrite and a different bacterial species oxidizes the nitrite to nitrate. Theoretically, approximately 4.5 mg/l of oxygen are required to oxidize 1.0 mg/l of ammonia (expressed as nitrogen) to nitrate. This theoretical value may conservatively over estimate the oxygen demand of nitrification as the nitrifiers obtain oxygen from inorganic carbon sources during combined energy and synthesis reactions. Actual values obtained have varied between 3.8 and 4.5 mg/l of oxygen per mg/l of ammonia nitrogen (NH_3-N). The Modified Iowa model uses 4.33 as the ratio of nitrogenous BOD to NH_3-N. Since secondary wastewater treatment plant effluents quite commonly contain NH_3-N levels of 10 mg/l during summer operations and 15 mg/l during winter periods, the equivalent nitrogenous BOD (should all the ammonia be converted to nitrates) is approximately 40-46 mg/l (summer) and 62-68 mg/l (winter).

Modified Iowa Model

The Modified Iowa model is a minor refinement of computer program used by the Department since 1976 to determine wasteload allocations (WLA). These refinements were recommended by the consulting firm, JRB Associates, McLean, Virginia, as part of the their review of the Department's water quality models. The specific modifications are presented in a User's Manual and described in detail later in this section. The major changes include: replacement of the existing temperature adjustments for nitrification rates, equations to account for algae uptake of ammonia, and a photosynthesis minus respiration (P – R) term for improvement of summer dissolved oxygen (DO) simulation. A copy of the complete user's manual is available from the Department (User's Manual for Modified Iowa DEQ Model, June 1983).

1. Dissolved Oxygen Deficit Equation

The Modified Iowa model uses a version of the Streeter-Phelps equation for DO deficit within the stream. This approach recognizes carbonaceous and nitrogenous BOD, atmospheric reaeration, initial DO deficit, and photosynthesis. The effects of photosynthesis and benthal oxygen demands are not specifically considered. The modified Streeter-Phelps equation suggested for use by JRB Associates is as follows:

$$D(t) = \frac{K_1 L_o}{K_2 - K_1}(e^{-K_1(t)} - e^{-K_2(t)}) + \frac{K_n N_o}{K_2 - K_n}(e^{-K_n(t)} - e^{-K_2(t)}) + D_o e^{-K_2(t)} + \frac{(R-P)}{K_2}(1 - e^{-K_2(t)})$$

where:

$D(t)$ = DO deficit at time t, mg/l
D_o = Initial DO deficit, mg/l
L_o = Initial ultimate carbonaceous BOD concentration, mg/l
N_o = Initial ultimate nitrogenous BOD concentration, mg/l
K_1 = Carbonaceous deoxygenation rate constant, base e, day $^{-1}$
K_N = Nitrogenous deoxygenation rate constant, base e, day $^{-1}$
K_2 = Reaeration rate constant, base e, day $^{-1}$
R = Algal respiration oxygen utilization, mg/l/day
P = Photosynthetic oxygen production, mg/l/day
t = Time of travel through reach, day

In this equation, the rates of oxygen utilization due to carbonaceous and nitrogenous BOD and algal activity are expressed as first order reaction rates. This is an accepted procedure for the carbonaceous demand, but represents a simplification for the nitrogenous demand. The "P – R" term represents the modification to the traditional Streeter-Phelps equations to account for algal influences to the available DO in the stream. The other traditional Streeter-Phelps components (Streeter, 1925) remain unchanged. The "P – R" term was obtained from the MS-ECOL fresh water model (Shindala et al., 1981).

The ultimate carbonaceous and nitrogenous BOD concentrations as a function of time (t) are calculated as follows:

$$L(t) = L_o e^{-K_1(t)}$$

$$N(t) = N_o e^{-K_n(t)}$$

where:

L(t) = Ultimate carbonaceous BOD at time, t, mg/l
N(t) = Ultimate nitrogenous BOD at time, t, mg/l

Since nitrification is a two-step process, many researchers have proposed that it is a second order reaction. However, most water quality models assume that it is a first order reaction for the ease of programming and usage.

Nitrifying bacteria are generally present in relatively small numbers in untreated wastewaters. The growth rate at 20°C is such that the organisms do not exert an appreciable oxygen demand until about eight to ten days have elapsed in laboratory situations. This lag period, however, may be reduced or eliminated in a stream due to a number of reasons including the following: the discharge of large amounts of secondary effluent containing seed organisms, and nitrifier population buildup on the stream's wetted perimeter. In biological treatment systems, substantial nitrification can take place with a resultant build-up of nitrifying organisms. These nitrifiying bacteria can immediately begin to oxidize the ammonia present and exert a significant oxygen demand in a stream below the outfall.

It is known that the biological nitrification process is generally more sensitive to environmental conditions than carbonaceous decomposition. The optimal temperature range for growth and reproduction of nitrifying bacteria is 26° to 30° C. It is generally concluded that the nitrogenous BOD will assume greatest importance in small streams which receive relatively large volumes of secondary wastewater effluents during the low flow, warm weather periods of the year (August and September). These conditions were used for the low flow determination of allowable effluent characteristics during summer periods. During winter low flow periods (January and February), nitrification will probably have limited influence upon the oxygen demand due to the intolerance of nitrifying bacteria to low temperatures. During analysis of winter low flow conditions, limited nitrification was observed.

2. <u>Respiration and Photosynthesis Equation</u>

The equations used to calculate P, the photosynethic oxygen production, and R, the algal respiration oxygen utilization, are:

$$P = \frac{(OP)\,(GP - DP)\,(CHLA)}{AP}$$

where:

OP = mg of oxygen produced by algae/mg of algae
AP = ug of chlorophyll–a/mg of algae
GP = Algal growth rate, day $^{-1}$
DP = Algal death rate, day $^{-1}$
$CHLA$ = Chlorophyll–a concentration, µg/l

and

$$R = 0.025\ CHLA$$

The values of OP, AP, and DP are selected from literature values. Current literature values are presented in Table IV-3 (page 72). It is essential that chlorophyll-a measurements be available from the stream sampling data. If not, chlorophyll-a values must be estimated by general field observation or conditions on a similar stream, which detracts from the credibility of the calibration. Since nitrate and inorganic phosphorus are not included in the model, the growth rate (GP) must be calculated outside the model using the equation:

$$GP = \mu \frac{(N)}{(N + K_{MN})} \frac{(P)}{(P + K_{MP})} \frac{(LI)}{(LI + K_{LI})}$$

where:

GP = Local algal growth rate at 20°C, day $^{-1}$
μ = Maximum specific algal growth rate at 20°C, day $^{-1}$
N = Sum of observed instream concentrations of NH_3-N and nitrate nitrogen (NO_3-N), mg/l
K_{MN} = Michaelis-Menton half saturation constant for total inorganic N, mg/l
P = Observed instream concentration of inorganic phosphorus, mg/l
K_{MP} = Michaelis-Menton half saturation constant for inorganic P, mg/l

LI = Average incident light intensity, kcal/m^2-sec
K_{LI} = Michaelis-Menton half-saturation constant for light, kcal/m^2-sec

Literature values for 〉, K_{MN}, K_{MP}, LI, and K_{LI} are shown in Table IV-3 (page 72).

The values of OP and AP are input as constants for the entire stream, while GP, DP, and CHLA are specified for each reach. The Michaelis-Menton constants are used to adjust the maximum potential algal growth rate by the amounts of light, nitrogen, and phosphorus that can limit algal growth. Each Michaelis-Menton constant is the concentration at which that particular constituent limits algal growth to half the maximal or "saturated" value.

3. Algal Uptake of Ammonia Equation

Another new feature in the Modified Iowa model is the simulation of the algal uptake of ammonia nitrogen (NH_3-N). The instream concentrations of inorganic nutrients are reduced by phytoplankton consumption. Phytoplankton requirements for inorganic N may involve both NH_3-N and nitrate nitrogen (NO_3-N). The fraction of consumed nitrogen which is NH3-N must be known if instream concentrations of NH_3-N are to be properly simulated. This fraction is the preferential NH_3 uptake factor.

The amount of NH_3-N removed by algae in a reach is calculated by the following equation taken from the MS-ECOL model (Shindala et al., 1981):

$$UP = \frac{(GP)(ANP)(NF)(CHLA)(e^{(GP-DP)(t)} - e^{-(K_N)(t)})}{(GP - DP + K_N)}$$

where:

UP = Amount of NH_3-N removed in a reach, mg/l
ANP = mg N/ug chlorophyll-a
NF = Fraction of NH_3 preferred for algal uptake (0 – 0.9)
t = Time of travel through reach, day

The model calculates 't' internally. The values of ANP and NF are obtained by calibration or from literature values. Ranges of literature values are found in Table IV-3 (page 72). The model assumes that algal uptake of ammonia occurs until the instream concentration of NH_3-N is equal to the inorganic N half saturation constant K_{MN}. If the instream concentration of NH_3 is below the half-saturation constant, the technical literature indicates that algae will switch to nitrate (NO_3) as the sole source of nitrogen.

4. Rate Constant Determination

a. Deoxygenation Rate Constants

The carbonaceous deoxygenation rate constant (K_1) for most streams will vary from 0.1 to 0.5 per day (base e, 20 °C). Early work by Streeter and Phelps (Streeter, 1925) determined an average value for the Ohio River of 0.23/day at 20°C (0.1/day, base 10). This value has been accepted and commonly used with reasonable results.

Specific deoxygenation rates for selected Iowa stream segments have been determined from stream surveys performed since 1977. These specific rates showed wide variations within each stream segment and among various streams. Thus, the carbonaceous deoxygenation rate of 0.2/day at 20°C is still used as an initial starting point in calibration/verification efforts. Future stream studies will be used to verify the specific rates applicable for Iowa streams.

Information on nitrogenous deoxygenation rates is extremely limited; however, available information indicates that nitrification rates (when active nitrification does occur) are somewhat greater than carbonaceous oxidation rates. Therefore, the nitrogenous deoxygenation rate (K_N) (0.3/day at 20°C was selected) is used as input data unless calibration/verification efforts provide a more reliable value. Again, future field measurements of typical nitrogenous deoxygenation rates in Iowa streams would greatly enhance the accuracy of the modeling effort.

The modified model alters the value of K_N within each reach as a function of the stream DO concentration. Because nitrifying bacteria are very sensitive to DO levels, K_N is reduced when low DO conditions exist. The following equation, which accounts for the effect of DO concentrations on nitrification rates, is taken from the Wisconsin QUAL III Model (WDNR, 1979):

$$PN = 1 - e^{-(0.52)(DO)}$$

where:

PN = Nitrification reduction factor
DO = Dissolved oxygen concentration, mg/l

The K_N value input to the model is multiplied by the reduction factor PN when DO concentrations are low. The product is the value of K_N, which is used in the DO deficit and nitrogenous BOD equations.

b. Reaeration Rate Constant

The relationship of Tsivoglou and Wallace (Tsivoglou, 1972) was adopted for determination of the reaeration rate constant. This formulation is based on the premise that the reaeration capacity of nontidal fresh water streams is directly related to the energy expended by the flowing water, which in turn is directly related to the change in water surface elevation.

The average rate of energy expenditure is found by dividing the change in water surface elevation by the time of flow. The original Tsivoglou and Wallace formulation has been modified to account for the percentage of ice cover. This relationship is expressed by:

$$K_2 = \frac{c\Delta h\,(ICE)}{t}, \text{ at } 20°C$$

where:

K_2 = Reaeration rate constant, 1/day, base e
c = Gas escape coefficient, 1/ft.
Δh = Change in water surface elevation, ft.
ICE = Factor reflecting effect of ice cover on reaeration rate (unitless)

$$1 - \left(0.95 \times \frac{\text{percent ice cover}}{100}\right)$$

t = Time of travel (days)

Tsivoglou's equation was derived from actual measurement of stream reaeration rates by a field tracer procedure in which a radioactive form of the noble gas krypton served as a tracer for oxygen. In development of Tsivoglou's procedure, other reaeration rate predictive formulas were compared with results obtained from the field tracer technique, but none appeared to predict stream reaeration rates as accurately as the Tsivoglou model.

The calibration results for sampled Iowa streams have indicated that the following guidelines are appropriate with respect to the gas escape coefficient incorporated in the Tsivoglou expression:

$$c = 0.054 \text{ (@ } 20°C\text{) for } 15 \le Q \le 3000 \text{ cfs}$$

$$c = 0.115 \text{ (@ } 20°C\text{) for } 0 \le Q \le 15 \text{ cfs}$$

Other calibrated/verified values may be used on streams with sufficient water quality data.

The ICE factor ranges from 0.05 for complete ice cover to 1.0 for zero cover. The selected input value is based on available field data or estimated by the modeler.

5. Temperature Corrections

Temperature corrections for the carbonaceous and nitrogenous deoxygenation rate constants and the reaeration rate constants are performed within the computer model. The following equations define the specific temperature corrections used in the program:

$$K_{1(T)} = K_{1(20)} (1.047^{(T-20)})$$
$$K_{2(T)} = K_{2(20)} (1.0159^{(T-20)})$$
$$K_{N(T)} = K_{N(20)} (1.080^{(T-20)})$$
$$GP_{(T)} = GP_{(20)} (1.047^{(T-20)})$$

where:

T = Water temperature, °C

This temperature correction for K_1 represents the state-of-the-art and is a widely accepted formulation. The K_2 and K_N equations represent the more accepted functions used in the Vermont QUAL-II model (Meta Systems, 1979). The growth rate temperature correction is taken from the MS-ECOL model (Shindala et al., 1981).

The principal factor affecting the solubility of oxygen is the water temperature. DO saturation values at various temperatures are calculated as follows:

$$C_s = 24.89 - 0.426T + 0.00373T^2 - 0.0000133T^3$$

where:

T = Water temperature, °F

C_s = Saturation value for oxygen at temperature, T, °F, at standard pressure

6. <u>Stream Velocity Calculations</u>

Stream velocities are important in determining reaeration rates and the downstream dispersion of pollutants. The computer model calculates velocity based on either a variation of the Manning's Formula for open channel flow or the Leopold-Maddock predictive equation.

a. Manning's Formula

The Manning's Formula for open channel flow is:

$$v = \frac{1.49R^{2/3} S^{1/2}}{n}$$

where:

v = Velocity, fps
R = Hydraulic radius, ft
S = Channel Slope ft/ft
n = Roughness coefficient

For a river or stream with a width much greater than its depth, the value of R is approximately equal to the mean depth. If both sides of the equation are multiplied by the cross-sectional area (width)(mean depth), the following equation results:

$$Q = \frac{1.49}{n} wd^{5/3} S^{1/2}$$

where:

d = Mean river depth, ft

Q = Discharge, cfs
w = Water surface width, ft
S = Slope ft/ft
n = Roughness coefficient

All variables except for "d" are input values. Internally, the program solves the above equation for d, then calculates the velocity v by:

$$v = Q/A = Q/wd$$

River slopes were obtained from existing stream profiles when available, but usually were taken from USGS topographic maps. Slopes obtained from USGS maps are rather generalized, and more accurate river profiles would greatly improve the accuracy of velocity determinations.
River widths were estimated from information obtained from field observations, flow, and cross-sectional data at each USGS gauging station.

Roughness coefficients are estimated from charts and techniques presented in Chow (Chow, 1965). The value of 0.035 is being used on Iowa streams unless the physical characteristics of the stream are more accurately reproduced by another value.

In developing the particular model run for a stream segment, depth and velocity data from stream gauging stations or from field surveys are used to extrapolate depth and velocity at other points along the segment. The extrapolation is a rough approximation; however, it is reasonably close over the average length of a stream. When available, the uses of field investigations to determine actual stream velocities and depths at many selected stream sites in the modeled segment have improved the accuracy of the model.

The Manning's equation is used where little historical flow and velocity information exists in the stream segment. If flows and velocities are measured during a calibration sampling event, the roughness coefficient "n" can be calibrated. However, in most instances, more reliable flow velocity relationships can be modeled by using the Leopold-Maddock equation.

b. Leopold-Maddock Equation

The Leopold-Maddock (Leopold, 1953) equation predicts stream velocity as a function of discharge according to:

$$V = aQ^b$$

where:

V = Stream velocity, ft/sec
Q = Discharge, cfs
a, b = Empirical constants

It is significant to point out that the empirical constants a and b apply to a specific stream cross section. The value of "b" represents the slope of a logarithmic plot of velocity versus discharge. The value of "a" represents the velocity at a unit discharge.

The Leopold-Maddock equation has been used in many studies and has been found to produce reliable results when the empirical constants are properly evaluated. However, its use is limited to streams for which historical data are not available for determining representative values for the empirical constants. A regression analysis is performed on several sets of velocity-discharge data to determine the empirical constants. The data selected for use in the analysis corresponds to low stream flow conditions since the use of elevated stream flow data may bias the results.

Since reaches of uniform cross section, slope, and roughness parameters rarely characterize stream systems, the empirical constants are determined for several representative cross sections of each stream system to be modeled. The same values of the empirical constants usually do not apply to all reaches along a stream segment unless field measured data indicates otherwise. JRB Associates staff indicated that a value for "b" of 0.25 is commonly used for smaller streams and rivers, such as those found in Iowa. Thus, where limited field information exists, "a" can be determined if "b" is assumed to equal 0.25 by solving the above equation. This assumption will only be used if there is insufficient flow or stream cross sectional data. Velocity and discharge values can be obtained from the USGS gauging station data forms 9-207 or from stream surveys obtaining current meter and cross section measurements.

7. <u>Computer Input and Output Data</u>

In order to calculate water quality at various points in the river, the river length to be modeled is divided into reaches. River characteristics (mean widths, depths, velocities, deoxygenation and reaeration rate constants, and water temperatures) were considered for each small reach. The overall stream length modeled should be less than 20 miles to insure steady state conditions.

One or more of the following set the location of the reaches:

a. A tributary.
b. A wastewater discharge.
c. A change in river characteristics, such as river width or slope.
d. A dam.

In order to calculate water quality characteristics at various points within each reach, the reaches are divided into segments called sections.

Actual data input into the computer program are as follows:

1. Initial river conditions such as flow and concentration of ultimate carbonaceous BOD, ammonia nitrogen (NH_3-N), and Dissolved Oxygen (DO).
2. Uniform background flow contributions for each reach and concentrations of ultimate carbonaceous BOD, NH3-N, and DO in the groundwater.
3. The number of reaches.
4. For each reach the following:
   a. Length
   b. Number of sections
   c. Water temperature
   d. Channel slope
   e. River width ——used in Tsivoglou & Manning equations
   f. Roughness coefficient
   g. Deoxygenation rate constants
   h. Empirical constants – Leopold-Maddock equation

i. Ice cover

5. Wastewater or tributary inflows consist of inflow rates, ultimate carbonaceous BOD, NH_3-N, and DO concentrations.

The computer printout of the model run includes a reformat of all input data and key calculated data for each stream reach and segment.

This calculated data includes:

1. Stream velocity
2. Rate constants
3. Saturated DO concentration
4. Travel time
5. BOD_u, NH_3-N and DO instream concentrations

An example of the output is found in the User's Manual for Modified Iowa DEQ Model.

TABLE IV-3
TYPICAL VALUES OF INPUT VARIABLES
FOR MODIFIED IOWA MODEL

VARIABLE	DESCRIPTION	RANGE OF VALUES	RECOMMENDED WLA VALUE
NF	Preferential NH_3 uptake factor	0 – 0.9	Calibrate
ANP	mg Nitrogen/ug Chlorophyll-a	0.0007 – 0.009	Calibrate
K_{MN}	Michaelis-Menton half-saturation constant for nitrogen (mg/l)	0.01 – 0.20	Calibrate
K_{MP}	Michaelis-Menton half-saturation constant for phosphorus (mg/l)	0.01 – 0.05	Calibrate
K_{LI}	Michaelis-Menton half-saturation constant for light (mg/l)	--------	0.0035
AP	ug Chlorophyll-a/mg Algae	10 - 100	Calibrate
OP	mg Oxygen produced by Algae/mg Algae	1.4 – 1.8	1.63
K_1	Carbonaceous deoxygenation rate constant (day $^{-1}$)	0.02 – 3.4	Calibrate
K_N	Nitrogenous deoxygenation rate constant (day $^{-1}$)	0.3 – 3.0	Calibrate
C	Tsivoglou escape coefficient (ft $^{-1}$)	--------	0.054, $15 \leq Q \leq 3000$ cfs 0.110, $1 \leq Q \leq 15$ cfs
〉	Maximum algal growth rate (day $^{-1}$)	1 - 3	2
DP	Local algal death rate (day $^{-1}$)	0.024, 0.24	Use higher value if nutrients are scarce or chlorophyll-a concentration exceeds 50 µg/l; otherwise use lower value
ICE	Factor relating ice cover to reduced reaeration capacity	0.05 – 1.0	Field observation

Vermont QUAL-II Model

The Vermont QUAL-II water quality model can simulate conservative and nonconservative constituents in branching stream and river systems. The constituents that can be modeled by the revised version of QUAL-II are:

- Dissolved Oxygen (DO)
- Biochemical Oxygen Demand (BOD)
- Temperature
- Algae
- Organic Nitrogen
- Ammonia Nitrogen (NH_3-N)
- Nitrite (NO_2-N)
- Nitrate (NO_3-N)
- Dissolved Phosphorus
- Organic Phosphorus
- Coliform
- Conservative Substances

The model was adapted for Iowa conditions and needs by JRB Associates. A copy of the detailed User's Manual can be obtained from the Department ("User's Manual for Vermont QUAL-II Model", June 1983). The User's Manual will provide documentation of the theoretical aspects of the model as well as a description of the model input and data requirements. The following discussion is, in part, key items from the User's Manual. The size

and complexity of the document prohibits its reproduction in this chapter of the "Basin Plan Support Document".

1. Background

The QUAL-II model is an extension of the stream model, QUAL-I, developed by F.D. Masch and Associates and the Texas Water Development Board in 1971. QUAL-I was originally designed to simulate the dynamic behavior of conservative materials, temperature, BOD, and DO in streams.

Water Resources Engineers, Inc. (WRE) revised the QUAL-I model to include the steady state simulation of NH_3, NO_2, NO_3, dissolved phosphorus, algae, and coliforms as well as DO and BOD. This WRE QUAL-II model has since undergone numerous revisions to incorporate additional parameters and changes in constituent interactions. The version of QUAL-II that is used by the Department is the Vermont version of QUAL-II.

The Vermont QUAL-II is basically a version developed by Meta Systems, Inc. (1979), with later modifications by Walker (1980, 1981) and the Vermont Department of Water Resources and Environmental Engineering (1981). The changes Meta Systems introduced in 1979 to U.S. EPA's version of QUAL-II include the following:

- Incorporation of the simulation of organic nitrogen.
- Provision of algal uptake of ammonia as a nitrogen source.
- Steady state calculation of diurnal oxygen variations due to algal photosynthesis and respiration based on diel curve analysis.
- Changes in the model to delete the dynamic simulation of DO, thus allowing dynamic simulation of temperature only.
- Inclusion of dam reaeration.
- Changes in the methods used to calculate the reaeration coefficient, K_2.
- Deletion of the radionuclide simulation.

Vermont later added this simulation of organic phosphorus and has modified the expressions for algal kinetics to the QUAL-II version developed by Meta Systems, Inc. (1979).[2]

2. Stream System Representation

QUAL-II permits any branching, well-mixed stream system to be modeled. It assumes that the major transport mechanisms, advection and dispersion, are significant only along the longitudinal axis of the stream. It can handle multiple waste discharges, withdrawals, tributary flows, incremental inflow, flow augmentation, and dam reaeration. Hydraulically, QUAL-II is limited to the simulation of time periods during which the stream flows in the river basin are essentially constant (Roesner, et al., 1981). Thus, the length of river or stream to be modeled is

relatively short, less than 20 miles. The length should be long enough to account for the decay of organic pollutants and the recovery to near background conditions. The use of this model is not suitable for one run over the entire stream or river length.

Streams to be simulated by QUAL-II are divided into reaches, and further subdivided into computational elements. River reaches are the basis of most data input. Hydraulic data, reaction rate coefficients, initial conditions, and incremental inflow data are constant for all computational elements within a reach. For the purposes of QUAL-II, the stream is

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[2] The majority of the information in the User's Manual came from the following four sources:

Meta Systems, Inc. Documentation for the Meta Systems Version of the QUAL-II Water Quality Simulation Model. July 1979.

Roesner, L.A., P.R. Giguere, and D.E. Evenson. Computer Program Documentation for Stream Quality Modeling (QUAL-II). EPA-600/9-81-014. Athens: U.S. EPA Center for Water Quality Modeling, Environmental Research Laboratory, February 1981.

Roesner, L.A., et al. User's Manual for Stream Quality Model (QUAL-II). EPA-600/9-81-015. February 1981.

State of Vermont, Agency of Environmental Conservation, Department of Water Resources and Environmental Engineering. Lower Winooski River Wasteload Allocation Study, Part B: Mathematical Modeling Report. January 1982.

conceptualized as a network of completely mixed reactors – computational elements – that are linked sequentially to each other via the mechanisms of transport and dispersion (Roesner, et al., 1981).

Streams to be simulated by QUAL-II are divided into reaches, and further subdivided into computational elements. River reaches are the basis of most data input. Hydraulic data, reaction rate coefficients, initial conditions, and incremental inflow data are constant for all computational elements within a reach. For the purposes of QUAL-II, the stream is conceptualized as a network of completely mixed reactors –

computational elements – that are linked sequentially to each other via the mechanisms of transport and dispersion (Roesner, et al., 1981).

Although QUAL-II has been developed as a relatively general program, Roesner, et al. (1981) cites certain dimensional limitations, which have been imposed upon it during program development. These limitations are as follows:

Reaches: a maximum of 75

Computational elements: no more than 20 per reach nor 500 in total

Headwater elements: a maximum of 15

Junction elements: a maximum of 15

Input and withdrawal elements: a maximum of 90 in total

QUAL-II makes certain assumptions about the stream system being simulated, including the following:

- QUAL-II assumes first order kinetics.
- The model utilizes a simplified nutrient-algal cycle with Michaelis-Menton kinetics.
- Only constant inflows and point source discharges are considered in the model.
- Each computational element is assumed to be completely mixed.
- The model does not take into account variations in depth or within stream cross section in each reach.

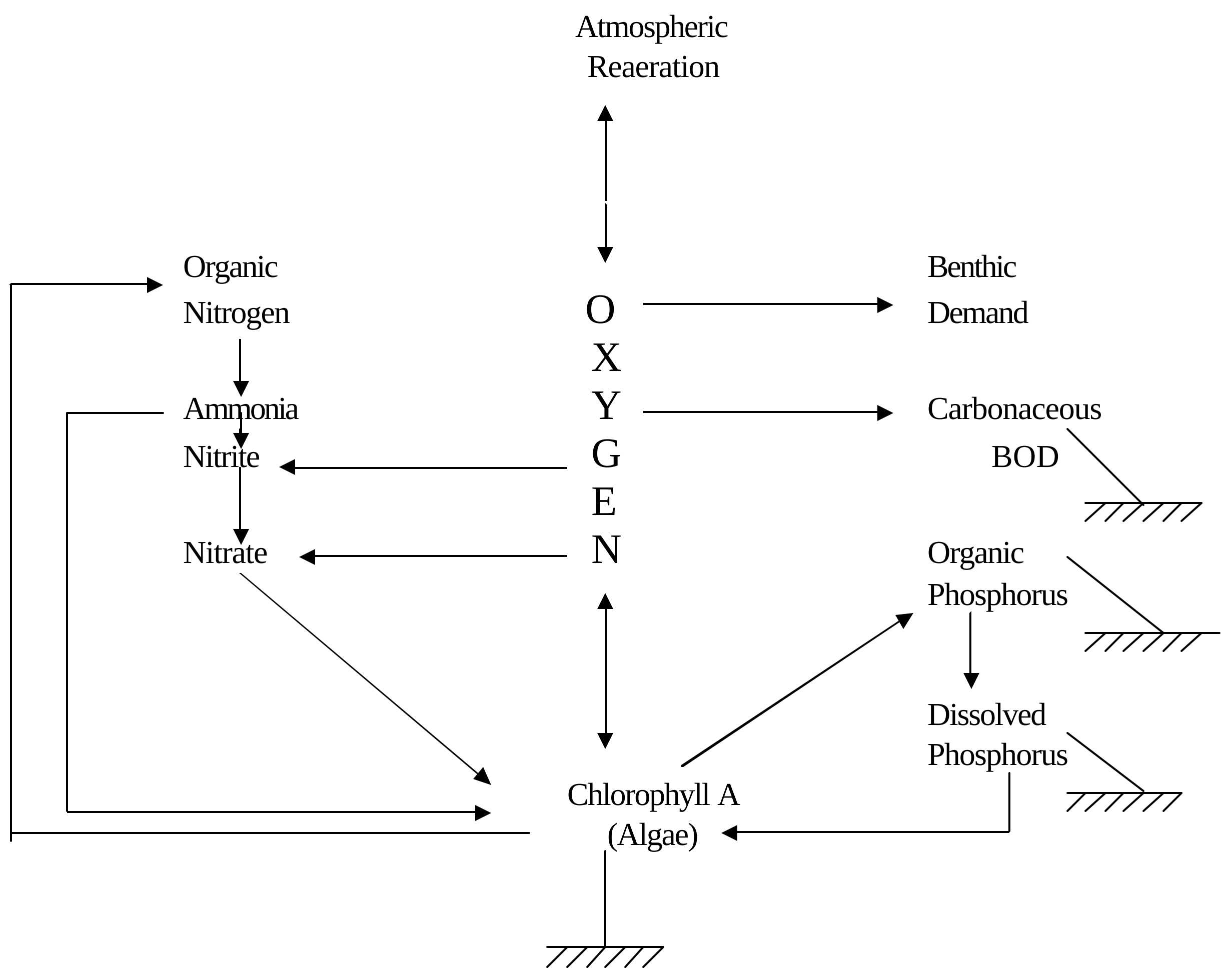
3. General Model Relationships

QUAL-II utilizes a mass balance differential equation that describes the behavior of a water quality constituent in one dimension. The model is structured to simulate the major interactions of the nutrient cycles, algal production, benthic oxygen demand, carbonaceous oxygen uptake, atmospheric reaeration, and the effect these processes have on receiving water concentrations of dissolved oxygen (DO). The interactions of all these constituents are illustrated in Figure IV-1. Arrows on Figure IV-1 indicate the direction of normal system progression in a moderately polluted environment; the directions may be reversed in some circumstances for some constituents. An example of process reversal: under normal conditions, oxygen will be transferred from the atmosphere into the water. Under conditions of oxygen supersaturation, which can occur as a result of algal photosynthesis, oxygen might actually be driven from solution, causing the direction of flow to reverse (Roesner, et al., 1981).

Coliforms are modeled as nonconservative decaying constituents, and do not interact with other constituents. The conservative constituents, of course, neither decay nor interact in any way with other constituents.

The detailed mathematical relationships that describe the individual reactions and interactions are presented in the User's Manual. Their inclusions would make this document very lengthy and cumbersome. A brief discussion on the mathematical relationships for phytoplanktonic algae is included, as this is one of the significant improvements over the past available model.

Figure IV-1
General Model Structure for QUAL-II



Source: Vermont, 1982

The chlorophyll-a concentration in a stream system is assumed to be directly proportional to the concentration of phytoplanktonic algal biomass. In QUAL-II, algal biomass is converted to chlorophyll-a by the simple relationship:

$$\text{Chl-a} = a_o A$$

where:

Chl-a = Chlorophyll-a concentration, µg/l
A = Algal biomass concentration, mg/l
a_o = A conversion factor – chlorophyll-a to algae ratio

The growth of algae (chlorophyll-a) is calculated according to the following differential equation:

$$\frac{dA}{dt} = uA - p_o A - \frac{s}{d}(A)$$

where:

A = Algal biomass concentration, mg/l
t = Time, day
u = The local specific growth rate of algae which is temperature dependent, 1/day
p_o = Algal death rate, 1/day
s = The local settling rate for algae, ft/day
d = Average depth, ft

It should be noted that the local algal growth rate is limited by light and either nitrogen or phosphorus, but not both. Thus, nutrient/light effects are multiplicative but nutrient/nutrient effects are alternate (Walker, 1981). The specific expression used to calculate local algal growth rates are listed in the User's Manual. In the QUAL-II model, the "algal respiration rate" controls only the uptake of oxygen by algae, while the "algal death rate" governs both the change in algal biomass due to endogenous respiration and the conversion of algal P to organic P. The "algal N to organic N" term represents the conversion of algal N to organic N. Algae are assumed to use ammonia and/or nitrate as a source of nitrogen. The effective concentration of available nitrogen is the sum of both concentrations. The algal growth rate and death rates are temperature dependent. They are corrected within the model, as are all other temperature dependent system variables, according to the procedure explained in the User's Manual.

4. Input Data

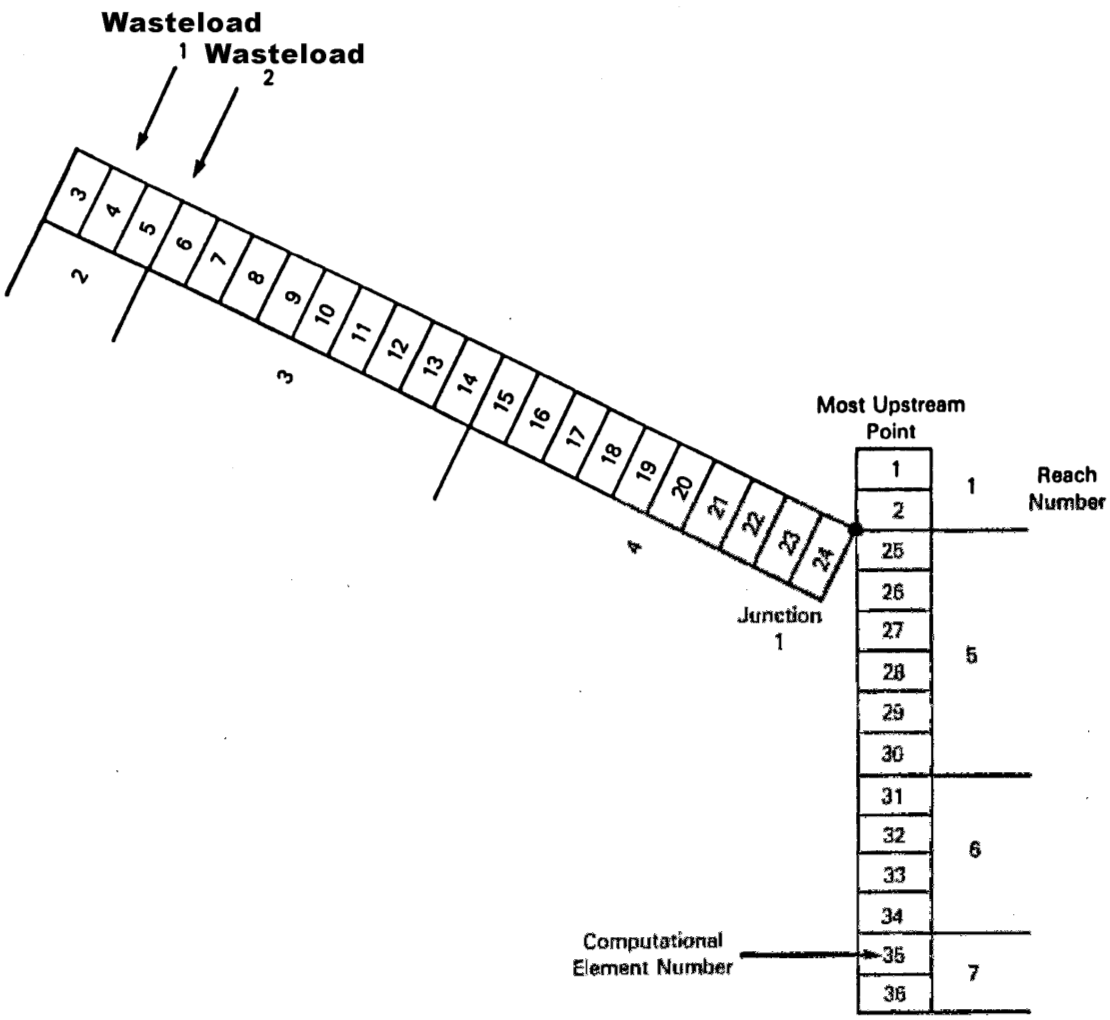
The first step in setting up the input data for QUAL-II is to prepare a graphic representation of the stream system, similar to that shown in Figure IV-2 (page 81). The best way to begin this is to locate the sampling stations, point source discharges, and stream junctions on USGS topographic maps. Stream miles can then be computed using a map wheel.

As shown in FigureIV-2 (page 81), the stream must be divided into reaches. Reaches are stretches of a stream that exhibit uniform hydraulic characteristics. The reaches are themselves divided into computational elements, which must be the same length throughout the stream system. The length chosen for the computational elements is determined by the degree of resolution needed to approximate the processes taking place in the stream. For example, if the observed dissolved oxygen (DO) concentration goes from saturated concentration to critical

concentration and back to saturated concentration over an interval of about five river miles, a degree of resolution of less than one mile is appropriate (Roesner, et al., 1981).

A sketch should be made of the stream reach configuration and the elements numbered. Each computational element is numbered sequentially, beginning with the uppermost point of the stream and proceeding downstream. When a junction is reached, the numbering scheme proceeds from the main stream element immediately upstream of the junction, to the uppermost point of the tributary, and continues downstream. Figure IV-2 (page 81) illustrates this numbering sequence.

Figure IV-2
Sample Reach Network



Source: Vermont, 1983

Each computational element in the stream reach network is classified into element types. These element types provide the location of discharges, withdrawls, tributaries, etc. The seven element types used in QUAL-II are:

Number	Type
1	Headwater source element
2	Standard element, incremental inflow only
3	Element on main stream immediately upstream of a junction
4	Junction element
5	Most downstream element
6	Input element
7	Withdrawal element

Special attention should be paid to the numbering of elements, particularly at the junctions. The point source loads are numbered downstream in the order of the elements. Any withdrawls are counted as a point source load in the numbering scheme. It is important that this be done correctly, since QUAL-II associates the first wasteload card with the first type 6 or 7 element in the stream configuration. The same is true of the order of the headwaters.

For informational purposes, the following types of input data groups show the complexity and flexibility of the QUAL-II program. These 12 groups each contain different categories of information that the user must supply to the program.

Card Type 0	Titles
Card Type 1	Control Data
Card Type 1A	Model Parameters
Card Type 2	Reach Identification
Card Type 3	Flow Augmentation Data
Card Type 4	Computational Element Flag Fields
Card Type 5	Hydraulic Data
Card Type 6	BOD and DO Reaction Rates
Card Type 6A	Algae, N, and P Constants
Card Type 6B	Other Coefficients
Card Type 7	Initial Conditions
Card Type 7A	Initial Conditions (continued)

Card Type 8	Incremental Runoff Conditions
Card Type 8A	Incremental Runoff Conditions (continued)
Card Type 9	Stream Junction Data
Card Type 10	Headwater Sources
Card Type 10A	Headwater Sources (continued)
Card Type 11	Point Source Inputs and Withdrawals
Card Type 11A	Point Source Inputs and Withdrawals (continued)
Card Type 12	Dam Reaeration Data

Specific input sequences and formats are presented in the User's Manual. Detailed procedures for calibrating the rate constants to specific stream conditions are also presented in the User's Manual. While running the program for a specific stream or for calibrating a segment, the suggested ranges for reaction coefficients are presented in Table IV-4 (pages 84-85). These values serve as a guide for a run of the QUAL-II program. Since the QUAL-II program is written in FORTRAN, it is essential that the input data be in the correct format for the program to run.

TABLE IV-4
RECOMMENDED RANGES FOR REACTION COEFFICIENTS
FOR QUAL-II

DESCRIPTION	UNITS	RANGE OF VALUES
Ratio of chlorophyll-a to algae biomass	ug Chl-a/Mg A	10 - 100
Fraction of algae biomass that is nitrogen	Mg N/Mg A	0.07 – 0.09
Fraction of algae biomass that is phosphorus	Mg P/Mg A	0.01 – 0.02
O_2 Production per unit of algal growth	Mg O/Mg A	1.4 – 1.8
O_2 Uptake per unit of algae respired	Mg O/Mg A	1.6 – 2.3
O_2 Uptake per unit of NH_3 oxidation	Mg O/Mg N	3.0 – 4.0
O_2 Uptake per unit of NO_2 oxidation	Mg O/Mg N	1.0 – 1.14
Rate constant for the biological oxidation of NH_3 to NO_2	1/Day	0.10 – 1.00
Rate constant for the biological oxidation of NO_2 to NO_3	1/Day	0.20 – 2.00
Rate constant for the hydrolysis of organic-N to ammonia	1/Day	0.02 – 0.4
Dissolved phosphorus removal rate	1/Day	0.02 – 0.4
Organic phosphorus settling rate	1/Day	0.001 – 0.10
Algal settling rate	ft/Day	0.5 – 6.0
Benthos source rate for phosphorus	Mg P/day-ft	Highly Variable
Benthos source rate for NH_3	Mg N/day-ft	Highly Variable
Organic P decay rate	1/Day	0.1 – 0.7
Carbonaceous deoxygeneration rate constant	1/Day	0.02 – 3.4
Reaeration rate constant	1/Day	0.0 - 100

RECOMMENDED RANGES FOR REACTION COEFFICIENTS
FOR QUAL-II
- Continued -

DESCRIPTION	**UNITS**	**RANGE OF VALUES**
Rate of loss of CBOD due to settling	1/Day	-0.36 to 0.36
Benthic oxygen uptake	Mg O/day-ft	Highly Variable
Coliform die-off rate	1/Day	0.5 – 4.0
Maximum algal growth rate	1/Day	1.0 – 3.0
Algal death rate	1/Day	0.024 – 0.24
Preferential NH_3 uptake factor	--------	0.0 – 0.9
Algal N to organic N decay rate	1/Day	0.11
Algal respiration rate	1/Day	0.05 – 0.5
Michaelis-Menton half-saturation constant for light	Langleys/min	0.02 – 0.10
Michaelis-Menton half-saturation constant for nitrogen	mg/l	0.01 – 0.20
Michaelis-Menton half-saturation constant for phosphorus	mg/l	0.01 – 0.05
Non-algal light extinction coefficient	1/ft	Variable
Algal light extinction coefficient	(1/ft)/(ug Chl-a/L)	0.005 – 0.02

MODELING DATA SOURCES

The bulk of the work in stream water quality modeling is the collection and interpretation of all available data describing the stream system to be modeled. This section describes procedures and data sources that may be used in stream modeling for wasteload allocations.

Wastewater Discharges

The required data for each discharger consists of effluent flow rates and effluent characteristics such as Biochemical Oxygen Demand (BOD), ammonia nitrogen (NH_3-N), Dissolved Oxygen (DO) concentrations, and temperature. The specific location and characteristics of some smaller wastewater discharges are often unknown and are determined from field investigations or during special stream surveys. Most wastewater discharge information is available in the departmental files.

River Miles

The first step in modeling a river system is determining the locations of all tributaries, wastewater dischargers, dams and other critical points along the river. The total length of the main channel of the river to be modeled must be established and river miles need to be located such that the location of tributaries, etc., can be determined to the nearest one-tenth of a mile. Often the U.S.G.S. or Corps of Engineers has located river miles on larger streams, but in some instances these river miles are incorrect or do not correspond to the existing stream channel. Experience has shown that it is best to start from the beginning with the best available base map and establish river miles by use of appropriate measuring techniques. The best maps to start with are U.S.G.S. topographic maps. These consist of section maps (scale: 1:250,000) and quadrangle maps (scale: 1:24,000). Other maps such as state and county road maps can also be used to supplement the U.S.G.S. maps.

Field Reconnaissance

The following data can be collected during special stream surveys:

1. The precise location of wastewater discharges.
2. The location, condition, height, and type of dams and the nature and approximate length of the pool created by the dam.
3. Approximate river widths at bridge crossings.
4. Approximate shape of channel cross sections.
5. Channel characteristics that will aid in determining the channel roughness coefficients.

The special stream survey should be performed, if possible, during flow conditions that represent the flows used in the modeling effort. Stream discharge information during stream surveys may be verified from data obtained from the U.S.G.S. The stream flow observed during stream surveys is often greater than the $7Q_{10}$. Data such as river widths need to be extrapolated downward to represent $7Q_{10}$ conditions. Shapes of channel cross sections are an aid in this determination.

River Channel Slopes

After river miles and locations are established, the next step is the determination of river channel slopes. During low flow conditions it can be assumed that river channel slopes are essentially the same as the slope of the water surface. Channel profiles can be used as representative of water surface slopes. In some cases, profiles of the river have already been determined. The U.S. Army Corps of Engineers usually does this as part of the work conducted prior to proposal or construction of flood control reservoirs. Without accurate profiles, river slopes can be determined from U.S.G.S. contour maps by locating the points where contour lines cross the river. Stream slopes that are calculated from contour maps only represent an average value over the distance of the river between contour intervals. U.S.G.S. quadrangle maps (if available) are a more reliable source of slope data. Often, these are the only sources available and are the best method of slope determination without an extensive field survey.

River Widths and Roughness Coefficients

River widths and roughness coefficients can be estimated during the field reconnaissance. Roughness coefficients can also be estimated using charts and techniques in hydraulic texts and handbooks. For further discussion, use Open-Channel Hydraulics by Chow, published by McGraw-Hill.

The variation of river widths with discharges can often be determined from data at U.S.G.S. gauging stations. The U.S.G.S. periodically calibrates each gauge. The results from these calibrations are available on U.S.G.S. form 9-207 and include widths, cross-sectional area, mean velocities, and discharges. Reasonably accurate estimations of river widths at the desired discharge can usually be made with this gauging station information along the river widths measured during special stream surveys.

Stream Flow

In the determination of flow conditions throughout the river system to be modeled, all available data from U.S.G.S. flow measuring stations as well as flow rates from all of the wastewater discharges must be obtained. River flows need to be allocated among tributary, groundwater, and wastewater inflow sources. The design low flow is used as the modeling basis, and is determined from a statistical analysis of the flow records at each of the gauging stations in the river system. Design low flows have already been determined for partial and continuous gauging stations (i.e. Iowa Natural Resources Council, Annual and Seasonal Low-Flow Characteristics of Iowa Streams, Bulletin No. 13, 1979). The design low flows at gauging stations must then be allocated to tributaries based on drainage areas. Tributary drainage areas may be available from existing publications (i.e. Larimer, O.J., Drainage Areas of Iowa Streams, Iowa Highway Research Bulletin No. 7, 1957) or they can be determined from U.S.G.S. contour maps.

A summation of tributary inflows and wastewater discharges often is less than the gauged flow. The difference is usually distributed along the main channel of the river as a uniform inflow in terms of cfs per mile of river reach length. If the gauged flow is less than the summation of tributary and wastewater inflows then it is possible to allot a uniform outflow from the main river channel.

Tributary and Groundwater Quality

Values for BOD, NH_3-N, and DO of tributary and groundwater inflow are required for stream modeling. Often, a main tributary to the stream being modeled has also been modeled. In this case, the water quality of the tributary just before discharge into the main stream (as determined by the model) is used. If the tributary is small and has several wastewater discharges, hand calculations can be done to determine its water quality just before entering the main stream.

If the tributary is free of continuous discharging wastewater facilities, water quality has been assumed to be good. The tributary water quality input values are: ultimate BOD – 6 mg/l; NH_3-N concentrations – 0.0 mg/l (summer), 0.5 mg/l (fall, winter, and spring); and DO at saturation.

Groundwater is also noted to be of high quality. The model input values for groundwater are ultimate BOD of 6 mg/l and NH_3-N at 0 mg/l. Groundwater DO's may be quite low depending on how it enters the stream. If it is subsurface flow, DO may be close to zero. A groundwater DO of 2 mg/l is used in wasteload allocation (WLA) work in Iowa.

Rate Constants

The reaeration rate constant (K_2) is usually determined from one of many available predictive formulas. The constant primarily used by the Department is based on Tsivoglou's formula.

Carbonaceous and nitrogenous deoxygenation rate constants are best determined experimentally for a specific wastewater effluent and/or calibrated for a specific stream. However, when specific values are not available, "typical" values from similar streams may be used. In most cases the carbonaceous deoxygenation rate constant (K_1) will not be less than 0.2 per day (20°C). Values as high as 3.4 per day (20°C) have been reported in the literature.

Less information is available on the nitrogenous deoxygenation rate constants or nitrification rates in streams. Experimental work in Illinois (State of Illinois, Environmental Protection Agency, Guidelines for Granting of Exemptions from Rule 404(C) and 404(F) Effluent Standards, Oct., 1974) determined that the nitrogenous deoxygenation rate constant (K_N) ranged from 0.25 to 0.37 per day with an average value of 0.29 per day at

20°C. The current model uses a K_N value based on stream calibration from the modeled stream or similar streams. Other rate constants for benthic and algal kinetics are based on calibration data or literature values. Specific explanations of these rate constants are in the User's Manual for the Modified Iowa and QUAL-II models.

Dams and Impoundments

The damming of a stream creates special conditions for water quality modeling. For modeling purposes, dams and the resulting impoundments can be put into one of two classifications.

1. Large dams that back up rather extensive impoundments. Flow through the impoundment is not "plug flow" and inflow may be dispersed in a variety of vertical and horizontal directions.
2. Low-head dams which essentially make the river channel wider and deeper for a maximum distance of several miles. Flow through the impoundment is primarily "plug flow."

Class 1 dams and impoundments cannot easily be modeled to predict water quality. The modeling effort should be stopped at the beginning of the impoundment and started again below the dam. Water quality below the dam can be estimated from knowledge of the size of the impoundment, the method of water withdrawal, and water quality data from stream surveys. Water taken from the lower levels of an impoundment during periods of summer stratification may be low in DO. If water flows over a spillway or an overflow weir it may be close to the DO saturation point. One can expect the BOD and NH_3-N concentrations in the discharge from large impoundments to be low unless the impoundment is highly eutrophic.

Class 2 dams and impoundments can be modeled by treating the impoundment as an enlarged or slower moving reach of the river. The length of the pool backed up by the dam may be divided into one or more reaches. Widths can be approximated from field observations. Slopes are taken as the water surface elevation and are quite small, generally elevation drops off no more than a foot over the length of the pool.

The dams may be treated as a reach 0.001 miles or 5.28 feet in length. The slope of this reach then becomes the dam height divided by 5.28 feet. The only water quality parameter that is significantly affected through the dam reach is the DO. Tsivoglou's reaeration rate constant prediction formula can be used to quite effectively predict reaeration over a dam. The equation for change in the DO deficit with time is:

$$D_t = D_o e^{-K_2 t}$$

where:

D_t = DO deficit at time, t
D_o = DO deficit at time zero
K_2 = Reaeration rate constant

Tsivoglou's reaeration rate constant predictive equation (neglecting ice conditions) is:

$$K_2 = \frac{c\Delta H}{t}$$

where:

c = Escape coefficient
ΔH = Change in elevation in time, t

Substituting into the DO deficit equation one obtains:

$$D_t = D_o e^{-c\Delta H}$$

Example:

With a dam 10 feet high and c = 0.115/ft. the ratio of D_t/D_o is 0.32 or the deficit is 32 percent of the deficit at time zero. This is a DO deficit recovery of 68 percent.

Winter Conditions Significance

Often the most critical period for maintaining water quality standards is during the winter design low flow periods instead of the summer period. Rates of deoxygenation are greatly reduced at the low temperatures, but ice cover also greatly reduces reaeration resulting in DO levels that may be critical. Nitrification is significantly reduced at freezing temperatures. Consequently, ammonia concentrations may remain elevated over long stream reaches. Some loss of ammonia may occur in stream reaches due to algal uptake.

During winter periods reaeration rates may need to be reduced in proportion to the extent of ice cover. Even with 100 percent ice cover a small amount of reaeration undoubtedly takes place. In the WLAs, reaeration rates were reduced in direct proportion to the estimated ice cover. The ice cover factor is assumed to vary in relationship with the amount of heated water in the discharge. The values range from 95% ice cover to 0% ice cover over dams. Research and field investigations are needed on the effects of ice cover on stream reaeration rates and the extent of ice cover on specific stream reaches in order to more precisely define the applicable reduction factor.

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APPENDICES

Appendix A

Minimum Protected Flow Policy Statement

The department will use the exception clause in Section 61.2(5) (departmental rules) to develop wasteload allocations (WLAs) for dischargers on intermittent and low flow streams. "Exceptions may be made for intermittent or low flow streams classified as significant resource warm waters or limited resource warm waters. For these waters, the department may waive the design low flow requirement and establish a minimum flow in lieu thereof. Such waiver shall be granted only when it has been determined that the aquatic resources of the receiving waters are of no significance at flows less than the established minimum, and that the continued maintenance of the beneficial uses of the receiving waters will be ensured. In no event will toxic conditions be allowed to occur in the receiving waters outside of mixing zones established pursuant to subrule 61.2(4)"(Chapter 61.2(5)).

The department will establish a minimum protected flow for the calculation of WLAs in selected Significant Resource and Limited Resource streams where it has been determined that the aquatic resources of the receiving waters are of limited significance at flows less than the established minimum. The use of minimum protected flows to calculate WLAs on intermittent and low flow streams will supersede the use of the natural design low stream flow. Calculation of WLAs will still use the procedures described previously.

Only the Significant Resource and Limited Resource stream segments with a natural design low flow of less than 2 cfs will be considered for establishing a protected flow. For the low flow streams, DNR Fish and Wildlife Division or Water Resources Section staff members will evaluate the fisheries' potential and other related aquatic organisms in the stream at the natural design low flow. The staff evaluation of the aquatic resources of low flow streams would place the streams in one of three categories:

Category 1: The first stream category would be typical meandering to channelized streams with silt to silt/sand beds in which water temperature equaled or exceeded 32°C during low flow periods. At this low flow condition, most higher tropic aquatic life has moved to deeper pools or to the main stream reaches. Thus, aquatic life for which the design use was considered for would not be present in significance numbers in the stream.

Category 2: The second stream category would consist of reaches where the background flow originated largely from spring or bedrock outcrops. Stream beds consist of silt/sand to sand and gravel. The stream temperature may range between 20° to 32°C with high tropic level aquatic life staying in the stream reach in small pools and underbank cuts.

Category 3: The third stream category would consist of reaches capable of supporting cold water aquatic organisms. Stream flow originates from springs with water temperatures less than 20°C. Stream beds consist of sand to sand and gravel. These stream reaches may be classified as cold water or tributaries to such stream reaches.

For those stream reaches under the first category, staff will recommend the specific protected flow level for each stream reach. This protected flow value may range from 1 to 2 cfs of natural background flow depending upon the normal aquatic organisms inhabiting the reach. Protected stream flows higher than 2 cfs would be considered if unique conditions have limited the normal aquatic organisms from inhabiting the stream reach at 2 cfs. Such conditions as depth of water, temperature, velocity, and substrate may be considered. Department staff will make careful documentation on such limiting conditions. For the second category streams, a protected flow of 1 cfs or less may be allowed. For the third category of streams, no protected flow will be used to calculate the WLA.

The effluent limitation, including ammonia, for any domestic discharger would be based upon this protected flow level added to any discharge flow originating from a point source discharger. The protected flow level will only be applicable along downstream reaches until the naturally occurring design low flow level is demonstrated to be greater than the protected flow level as determined above, or a significant source of stream flow entered the reach to support the designated aquatic uses. The establishment of protected flows will not apply to facilities that discharge to High Quality Resource waters.

Appendix B

Procedure for Gathering Site Specific Data:
pH and Temperature Data and Mixing Zone Study for a NPDES Applicant

Wastewater treatment facilities are encouraged to plan ahead when considering any data gathering effort. Many of these efforts require seasonal data particularly collected during low stream flow conditions. A time span of several years may be necessary to gather adequate data during the critical stream flow conditions.

A. Effluent pH and Temperature Data

Facilities are encouraged to obtain site specific field data of the receiving stream's pH and temperature conditions. This data would be used in place of the statewide default data used in the WLA calculations. Where the discharge is into a shallow or marshy area that has no clear channel or there are considerable backwater effects from a downstream dam or river, information should be obtained on the waterbody and discharge pH and temperature. The facility can provide information on the actual effluent pH and temperature during various months to demonstrate that the statewide values used by the department were not representative of the facility and/or the receiving stream. This may help reduce the need for stringent ammonia limits.

Approximately two years of data may be necessary to establish representative site specific data. Discussions between Department staff and the wastewater facility staff should occur before performing the data collection to establish an acceptable scope of work. Information should be obtained in a similar manner to that stated in the Ammonia section (pages 13-16). More information about collecting pH and temperature is contained in the Ammonia section.

Simplified Mixing Zone Study

The following are the basic field data requirements for two types of mixing zone (MZ) studies. This field data is to be provided by a National Pollutant Discharge Elimination System (NPDES) applicant for recalculation of the local MZ. The purpose of the recalculation is to more closely approximate the local MZ using site specific data instead of statewide data. Contact should be made with the department's Water Quality Resources Section staff prior to beginning any field study.

1. Stream Characteristics

It should be noted that the terms low flow and low stream flow are used in the following discussion. These terms are not synonymous with the design low flow or protected flow. The facility can provide information on the actual mixing zone characteristics during **low stream flow conditions** to demonstrate that a greater percentage of the low stream flow is mixing with the effluent than projected by the Department.

Stream surveys to gather mixing zone data should be collected as near to the design low flow or protected flow as is normally feasible during the summer months of the year. A mixing zone study should be performed at stream flows not exceeding 3 to 5 times the design low flow or protected flow. Stream flow conditions closer to the design low flow are desirable for those locations where normal flows during the year approach the design low flow or where the flows are controlled by impoundments. This type of study may help reduce the need for stringent ammonia (or metals) limits. Several different field efforts are being considered in obtaining the mixing zone information, Visible Assessment, Dye Injection – Visible Boundary, and Dye Injection – Fluorometric Measurements.

a. Visible Assessment: This procedure is a simple field documentation of the effluent's mixing with the stream under low stream flow conditions. Pictures, video, drawings, or a more detailed map along with some physical stream data should be provided to illustrate how the two waters (effluent and receiving stream) are combining. Typically, the effluent can be seen (foam, turbidity, or color differences) to mix with the stream. Some facilities have added dye to the effluent to facilitate the visible assessment. This approach should be adequate on a smaller, shallow stream. A letter of authorizing the discharge of dye will be required from the Department before dye can be introduced into the stream.

Several municipal facilities have seen the effectiveness of this approach. The objective is to demonstrate whether or not the effluent flow is <u>completely</u> mixing with the stream within the allowed mixing zone length. Therefore, if this approach provides valid data, the facility would receive all of the design low flow or protected flow for waste assimilation of ammonia and toxics. With no additional documentation on the mixing characteristics in the zone of initial dilution, default of 5% design low flow will be used for the ZID in the WLA calculation.

- The visible assessment description should include the following items for a distance of 2000 feet downstream (unless other distance limitation is known to apply) and 200 feet upstream of the outfall:
  (1) Describe the stream bed materials: sand, fine or coarse gravel, mud, or rock.
  (2) Note pools and riffles and areas of uniform depths. Estimate length and number thereof and the rapidity of the variations (i.e. gradual, alternating occasionally, or alternating frequently).
  (3) Describe the amount of weed growth and snags in the stream in terms of negligible effects on the stream flow to severe effects on the stream flow.
  (4) Describe the amount of meandering within the 2000 feet distance.
  (5) Describe other features which might effect the MZ such as delta formation at the stream mouth, other discharges, perennial springs, etc.

- A description is needed of the outfall during a low stream flow period. This should include an indication of the discharge flow during the period being described, preferably with pictures. Describe such things as the size and configuration of splash pools, outfall height or depth, outfall diameter (if normally filled during discharging), and/or average velocity of flow exiting outfall when submerged.

- The Department encourages the submission of additional field data. This would include at least two cross sections of the stream at low flow, one at an upstream location and one at the anticipated MZ. Each cross section should include a minimum of 10 depth measurements (depths taken at least every two feet if stream width is less than 40 feet and at least every 5 feet if less than 100 feet, otherwise every 10 feet). Stream velocities should be provided if the dilution ratio is less than 3:1, one upstream, one at the anticipated mixing zone, and one spaced evenly downstream of the outfall and the MZ. If there are several pools and riffles, additional cross sections are needed to provide a more accurate indication of average depths.

b. Dye Injection – Visible Boundary Measurements: The objective of this procedure is to provide greater accuracy in characterizing the mixing of an effluent with the receiving stream by using a visible dye injected into the effluent. The following is a brief summary of the procedures that should be followed:

1. Lay out downstream station locations along shoreline at interval of 50', 100', 200', 500', 1000', 1500', and 2000' below the outfall.
2. Assemble boundary marking floats or stakes. Test stream depth for float line length and ability to wade.
3. Run short test of dye introduction into the effluent. The dye introduction is normally poured as a slug of dye into the effluent at the last manhole or at the outfall.
4. Run actual dye study and set out markers. Time of travel between stations may also be obtained, if desired.

5. Measure stream flow, (depth, velocity, cross section) at selected downstream sites and upstream of outfall. It is important to determine the amount of flow in the dye plume at both the MZ and ZID locations. Obtain effluent flow measurement at time of dye injection.
6. Prepare a report of the findings.

This will take a field crew of three people approximately two days to complete. The data assembly and preparation of the report will take several days. This is not a widely used type of study, but it is able to provide quantifiable data, particularly on larger waterbodies. The procedures may be modified if needed for specific stream conditions. Data results need not show 100% mixing. The key is to perform the study at or near design low stream flow conditions. Models are available to project the percentages of mixing obtained during field flow conditions to design low flow regime.

c. **Dye Injection - Fluorometric Boundary Measurements:** The objective of this procedure is to provide even greater accuracy in characterizing the mixing of an effluent with the receiving stream by using a florescence dye injected into the effluent. This is a rarely used approach as it is more staff intensive, but it has provided very quantifiable results.

This study is very similar to the Visible Dye effort noted above, however, the actual measurement of dye concentrations (or collection of water samples for later analysis) will be made at various locations in the mixing zone. The dye will be fed into the effluent at a constant rate/concentration over the duration of time required to collect all dye samples. The collection of dye samples (or measurement of concentrations) will be made across the stream from the shoreline until a point in the stream where no additional dye is expected. The same station locations will be used starting at the lower location and proceeding upstream. Stream flow measurements as noted above also will be required. This will take a field crew of three to four people approximately two to three days to complete. The data assembly, analysis, and preparation of the report will take several days.

2. Use of Mixing Zone Study Results

The Department will use the mixing zone study results to recalculate WQ-based permit limits. It is important to note that the level of accuracy is greatly improved by providing site specific data of the Mixing Zone (and ZID if applicable) while still ensuring that the WQS are met at any point along the mixing zone boundary. It is recommended that the Mixing Zone study be performed prior to NPDES Permit re-issuance. This makes re-issuance less controversial. When it is not feasible to complete a Mixing Zone study prior to the permit re-issuance, the Mixing Zone may be an item of the compliance schedule. The Water Resources Section can provide the facility with preliminary WQ-Based permit limits to aid in evaluating the need for Mixing Zone study. It is recommended that contact be made with the Water Resources Section staff to discuss the scope of a mixing zone study and receive necessary variances if dye is to be injected into the stream.

C. Installation of a Diffuser

Several facilities have constructed an instream diffuser to disperse their effluent across a more significant portion of the stream. This is an artificial means to increase the mixing zone. Typically 75 - 80% of the low stream flow is passed across a diffuser. Several facilities have designed diffusers to force 100% of the low flow across the diffuser. Partially buried pipe with risers or rock encased perforated pipe are being used. Several permits may be required for this type of structure. No mixing zone study is needed for the use of a diffuser. However, a follow-up stream study will be required to demonstrate that the diffuser is working properly.

Mixing Zone Calculations

The mixing zone (MZ) dispersion model used by the department staff is based upon an equation obtained from EPA contractors involved with toxics modeling. This equation is a 'Far Field' analytical solution for mixing in a river where the discharge is uniformly mixed from top to bottom of the river. The original equation has been adjusted to incorporate a near shore discharge rather than a mid-channel discharge. The equation used is:

$$C = \frac{Q_o C_o e^J}{(2)(d)(K)} \qquad (1)$$

where:

C = Concentration in the river at location x, y, mg/l
C_o = Concentration of the discharge, mg/l
Q_o = Discharge flow, cubic feet per second
d = Average stream depth, ft.
u = Average stream velocity, ft./sec.
x = Distance downstream from the discharge, ft.
y = Distance from the discharge side of the shore, ft.
$K = (\pi D_y u x)^{0.5}$
$J = (-uy^2) / (4D_y x)$
D_y = The lateral dispersion, square feet per second

The lateral dispersion is found from the equation:

$$D_y = (\alpha)(d)(u_s) \qquad (2)$$

where:

α = A proportionality variable which varies with the stream. It is normally about 0.6 ± 0.2, but it can vary from a value of 0.1, which has been found in experimental plumes, to larger than 0.8, which has been found in natural channels. For most rivers in Iowa it is expected to be larger than 0.4, and will normally be assumed to be 0.6.

$$u_s = \text{The shear velocity} = (1/8fu^2)^{0.5} \qquad (3)$$

f = The Fanning or Darcy-Weisbach friction factor, which can be found from diagrams in various references. Note: To facilitate the development of wasteload allocations, an approximation for f was developed. The developed equation is not accurate for f at all Reynold's numbers or (e/d)'s. The equation is:

$$f = (4)(0.01895)(e/d)^{0.5} + 0.001701 \quad (4)$$

e = Is the size of the roughness of the channel. An equation was developed from limited experimental data which indicated reasonable fit to an equation for:

$$(e/d) = 1/(L + 0.001)(Q_r + 2.6) \quad (5)$$

$$L = (15{,}000^{\,1.2})(Q_r^2)$$

Q_r = River flow rate, cfs

Equation (1) is solved for C at varying locations (x, y) and rounded to five decimal places. The y locations where C equals zero are then taken to be the width of the plume. The flow in the plume at that point is calculated to be the plume width times the average river depth times the average river velocity.

The acute and chronic wasteload allocations (WLAs) are determined using the flow in the MZ or Zone of Initial Dilution (ZID) from the previous criteria, the discharge flow, the background concentration, and the water quality standard. The equation for the WLA is:

$$C_o = [C_s\,(Q_b + Q_o) - Q_bC_b] \,/\, Q_o \quad (6)$$

where:

C_o = WLA
C_s = The acute or chronic water quality standard
Q_b = Stream flow in the MZ or ZID
Q_o = Discharge flow
C_b = The background concentration

Inputs Into the Mixing Zone Calculations

Development of the flow, width, average depth, and average velocity values used in the above equations is developed either from a separate set of equations or from actual field data. Where a cross section of the river and flow rate is known at or close to the point of discharge, the field cross section and velocities are used along with slopes from U.S.G.S. topographic maps to determine Manning's "n" for the river at that flow. (If slope is measured in the field this may improve the quality of the information from these equations since significant differences in slope from the topographic map may occur). The equations used are:

$$Q_r = (W)(d)(u) \qquad (7)$$

where:

W = Width of river

$$d = W / (W/d) \qquad (8)$$

where:

(W/d) = A ratio determined from the field data

$$rH = \text{Hydraulic radius} = (W)(d) / (2W) + (2d) \qquad (9)$$

Note: The hydraulic radius is actually a ratio of the area of stream cross section to the wetted perimeter of the stream. Improvements in the equation used to obtain the hydraulic radius will probably improve the quality of the information from this set of equations. The above equation is based on the hydraulic radius for a rectangle (Perry's Chemical Engineers' Handbook 4th Edition, pages 5-20).

$$u = (1.49 /n)(r_H^{\ 2/3})(S^{\ 0.5}) \qquad (10)$$

where:

n = Manning's n

S = Slope

The Manning's n and (W/d) ratio determined from the above equations are then adjusted to the design low flow (dlf) using:

$$n_{dlf} = (n_{orig})(Q_r / Q_{dlf}) \quad (11)$$

$$(W/d)_n = (W/d)_{orig}(Q_r / Q_{dlf})(d/d_a) \quad (12)$$

where:

d_a = The average depth without the first and last reading in the cross section

These are then used with the above equations to determine the average velocity and average depth of the river at the design low flow. A line can then be plotted across the previous cross section to represent the new surface level. The new surface level is found by subtracting the new average depth from the old average depth. The method used has normally shown less than 10 percent difference between the length of the new line representing the new surface width and the calculated width of the river obtained using equation (7).

Where no field information exists, it is difficult to predict the width, depth, and velocity of a river. The department will normally adjust W, (W/d), and n to predict a width, depth, and velocity using equation (7), (9), and (10) to provide a range of acceptable numbers.

Appendix C

Iowa Permit Derivation Methods

Definition of Variables:

WLA_a = Acute Wasteload Allocation
WLA_c = Chronic Wasteload Allocation
CV = Coefficient of Variation
n = Sampling Frequency
MDL = Maximum Daily Limit
AML = Average Monthly Limit

Statistical-Based Procedure:

The modified 1991 EPA Technical Support Document (TSD) methodology is adapted for the Iowa statistical-based procedure to derive the permit limits from the wasteload allocations. The following section describes the different procedures used to derive the permit limits for ammonia and toxics.

1. Ammonia

   MDL = WLA_a
   If $WLA_c < WLA_a$, AML = WLA_c
   Otherwise, AML = MDL = WLA_a

2. Toxics

First, a treatment performance level (LTA and CV) needs to be determined to allow the effluent to meet the WLA requirement. Where two requirements are specified based on different duration periods (i.e., WLA_a and the WLA_c), two performance levels are calculated.

The LTA_a is determined by the following equation:

$$LTA_a = WLA_a e^{\left[0.5\sigma^2 - z\sigma\right]}$$

$$\text{where } \sigma^2 = \ln\left(CV^2 + 1\right)$$

The LTA_c is determined by the following equation:

For 4-day chronic averaging period (i.e., for toxics):

$$LTA_c = WLA_c e^{\left[0.5\sigma_4^2 - z\sigma_4\right]}$$

$$\text{where } \sigma_4^2 = \ln\left(CV^2 / 4 + 1\right)$$

The z value for the LTAs is based on a 0.01 probability basis, i.e. the 99th percentile level, with a value of 2.326. The default CV value is 0.6 unless applicable data is provided by the wastewater treatment facility.

Next, permit limits are derived directly from the corresponding LTA value; in other words, the MDL is calculated from LTA_a and the AML is calculated from the LTA_c.

The MDL is calculated by the following equation:

$$MDL = LTAe^{\left[z\sigma - 0.5\sigma^2\right]}$$

$$\text{where } \sigma^2 = \ln\left(CV^2 + 1\right)$$

The z value for MDL is based on a 0.01 probability basis, i.e. the 99th percentile level, with a value of 2.326.

The AML is calculated using the equation:

$$AML = LTAe^{\left[z\sigma_n - 0.5\sigma_n^2\right]}$$

$$\text{where } \sigma_n^2 = \ln\left(CV^2 / n + 1\right)$$

The z value for AML is based on a 0.01 probability basis, i.e. the 99th percentile level, with a value of 2.326. The monitoring frequency (n) will follow the requirements noted in the department's rule, Chapter 63. However, the n value used to calculate the AML should always be greater or equal to **4/month** to guarantee meeting the criterion.

If the above calculated AML is greater than the MDL, set AML = MDL.